Australian Government

ansto

Nuclear-based science benefiting all Australians

Accelerator Mass Spectrometry & Ion Beam Analysis at ANSTO's Centre for Accelerator Science

A.M. Smith (and a cast of thousands!)

Australian Nuclear Science and Technology Organisation (ANSTO), Locked Bag 2001, Kirrawee NSW 2232, Australia.

New User Symposium, Australian Synchrotron, 6th September 2016, National Centre for Synchrotron Science

overview

- What is the *Centre for Accelerator Science (CAS)?*
- What are *particle accelerators* and *how do they work?*
- What is *'Accelerator Mass Spectrometry' (AMS)?*
- What is *Ion Beam Analysis (IBA)?*

- Example: ^{14}C or 'radiocarbon'.

Centre for Accelerator Science at ANSTO

$25M Australian Federal Government (2009) + $13M ANSTO towards upgrading the existing accelerator facility (now $65M)

CAS project leader: Michael HOTCHKIS

Project Manager: Jason COWAN & Shane HARRISON

Construction Supervisor: Mark HARRIS

Building construction: KANE PTY LTD

Architects: DARYL JACKSON ROBIN DYKE PTY LTD

National Electrostatic Corporation Accelerators: Eric ALDERSON, Alan OCONNOR, Richard KITCHEN, …

Accelerator Operations: David BUTTON, Philip CHATFIELD, Andrew DOWNES, Peter DREWER, Oliver EVANS, David GARTON, Shaun KOZANIC, Shane LONG, Damien LYNCH, Michael LYNCH, Michael MANN, Tony MOWBRAY, Craig Robert THOMPSON, Jian WANG

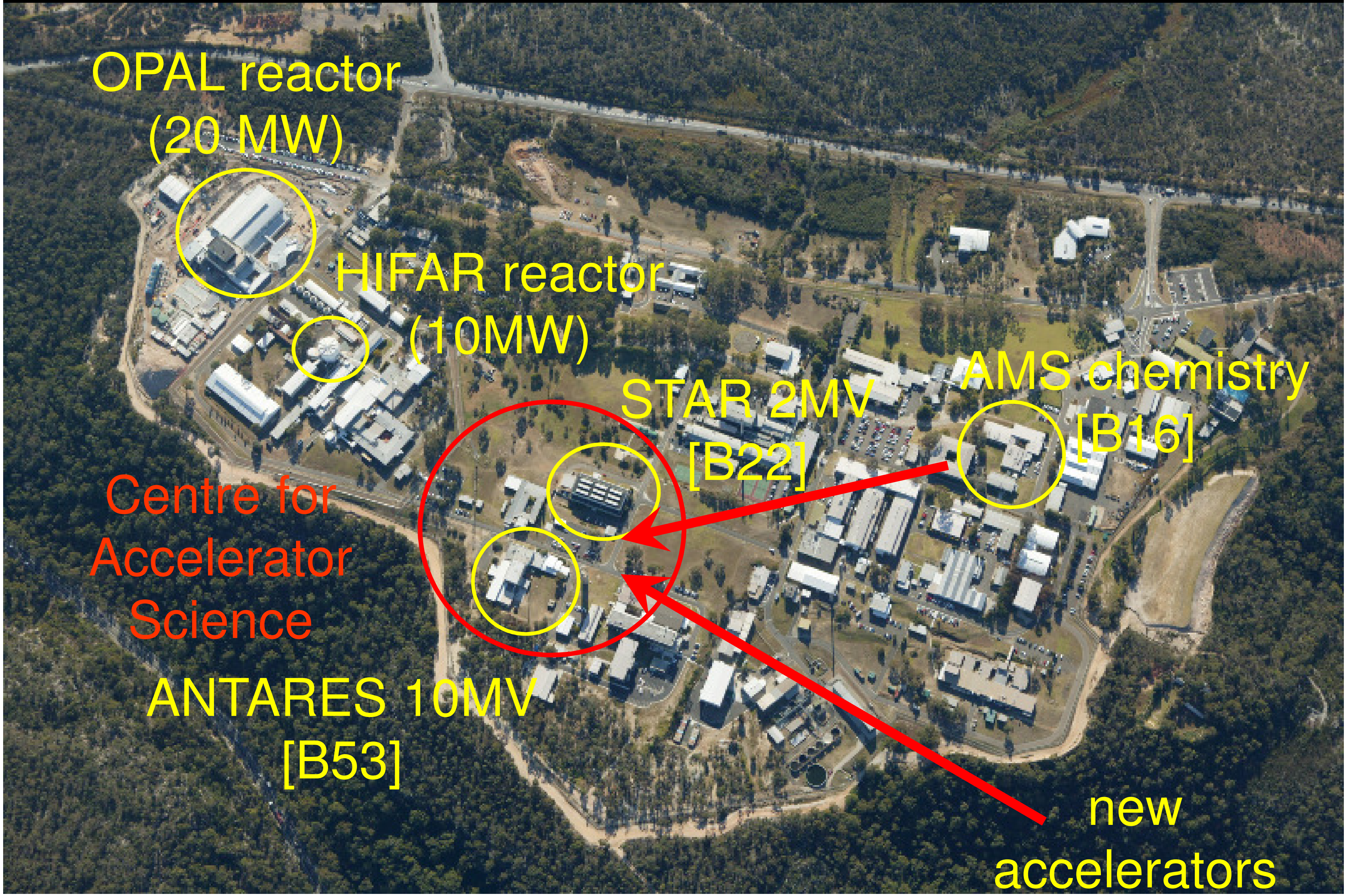
Accelerator Mass Spectrometry Scientists: David CHILD, David FINK, Toshiyuki FUJIOKA, Michael HOTCHKIS, Quan HUA, Andrew JENKINSON, Vladimir LEVCHENKO, Andrew SMITH, Klaus WILCKEN, Bin YANG

Accelerator Mass Spectrometry chemists: Linda BARRY, Fiona BERTUCH, Brodie BISHOP, Geraldine JACOBSEN, Steven KOTEVSKI, Shwaron LAL, Charles MIFSUD, Tan NGUYEN, Prabha PRATAP, Krista SIMON, Simon SIMON, Simon VARLEY, Alan WILLIAMS

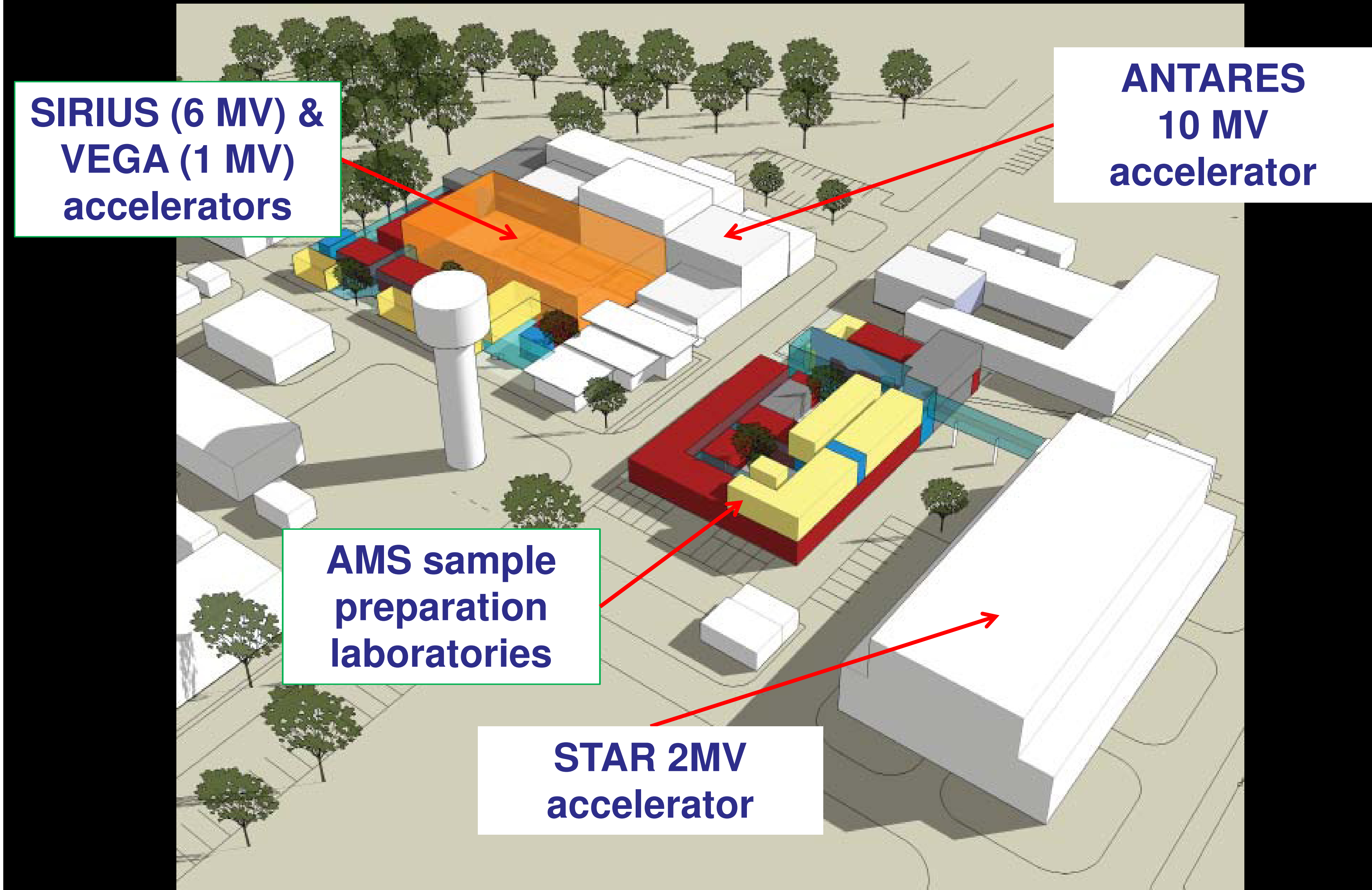
Ion Beam Analysis Scientists: Armand ATANACIO, David COHEN, Mihail IONESCU, Zeljko PASTUOVIC, Rainer SIEGELE, Ed STELCER

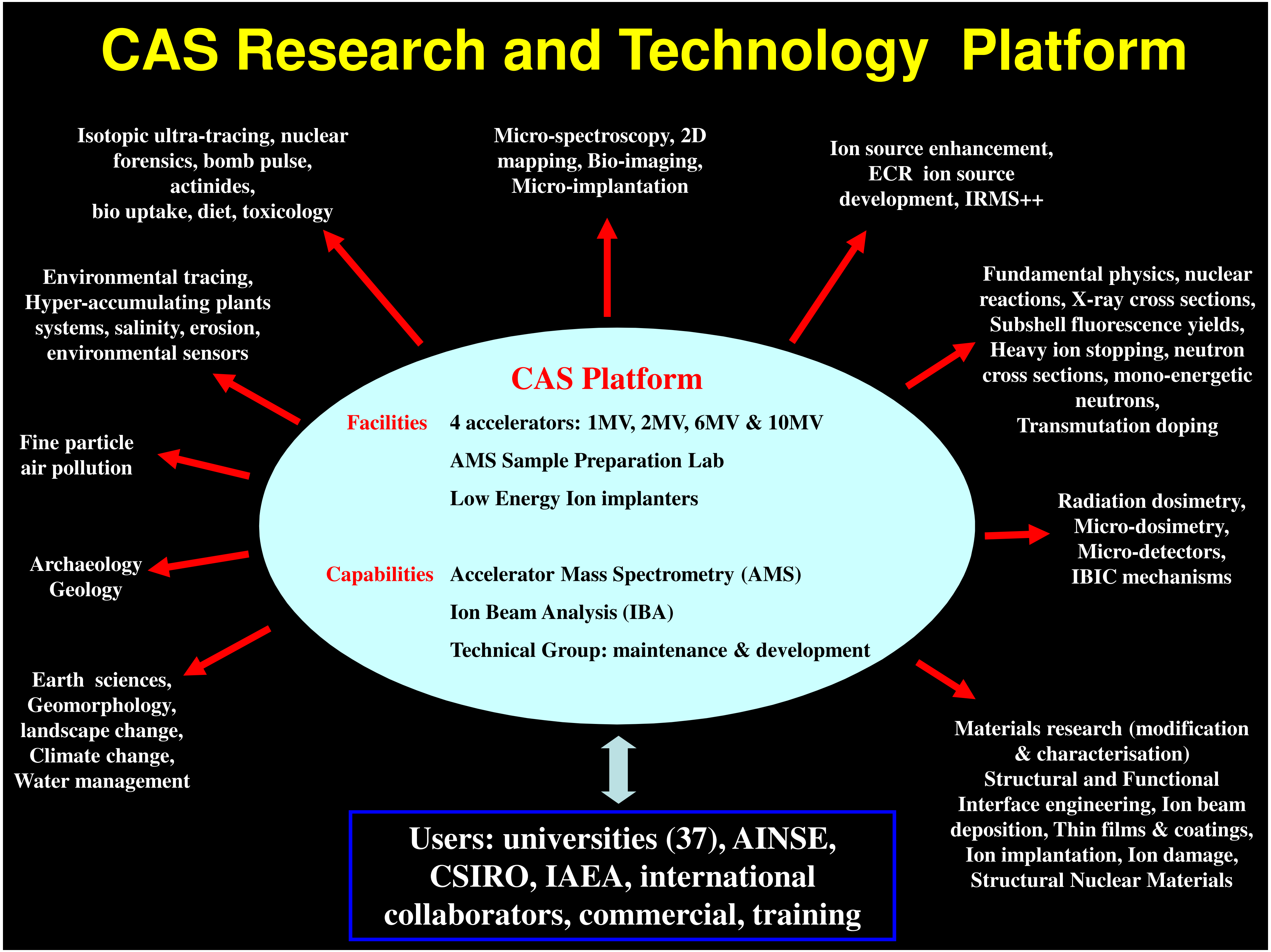
ANSTO support staff & contractors: MANY!

Australian Nuclear Science and Technology Organisation
Lucas Heights, Sydney



Centre for Accelerator Science




CAS Research and Technology Platform
Isotopic ultra-tracing, nuclear forensics, bomb pulse, actinides, bio uptake, diet, toxicology
Micro-spectroscopy, 2D mapping, Bio-imaging, Micro-implantation
Ion source enhancement, ECR ion source development, IRMS++
Environmental tracing, Hyper-accumulating plants systems, salinity, erosion, environmental sensors
Fundamental physics, nuclear reactions, X-ray cross sections, Subshell fluorescence yields, Heavy ion stopping, neutron cross sections, mono-energetic neutrons, Transmutation doping
Fine particle air pollution
CAS Platform
Facilities
4 accelerators: 1MV, 2MV, 6MV & 10MV
AMS Sample Preparation Lab
Low Energy Ion implanters
Capabilities
Accelerator Mass Spectrometry (AMS)
Ion Beam Analysis (IBA)
Technical Group: maintenance & development
Radiation dosimetry, Micro-dosimetry, Micro-detectors, IBIC mechanisms
Archaeology Geology
Earth sciences, Geomorphology, landscape change, Climate change, Water management
Materials research (modification & characterisation) Structural and Functional Interface engineering, Ion beam deposition, Thin films & coatings, Ion implantation, Ion damage, Structural Nuclear Materials
Users: universities (37), AINSE, CSIRO, IAEA, international collaborators, commercial, training

Centre for Accelerator Science: CAS

Three user groups:

- AMS (Accelerator Mass Spectrometry).
  AMS samples go into the ion source.
- IBA (Ion Beam Analysis).
  IBA samples go into the end stations.
- ASD (Accelerator Systems and Development)
  Maintenance and development.

CAS facilities

Four <u>tandem</u> accelerators:

- ANTARES: 10MV, HVEC, 1988, AMS & IBA
- STAR: 2MV, HVEE, 2003, AMS & IBA
- VEGA: 1MV, NEC, 2014, AMS
- SIRIUS: 6MV, NEC, 2015, AMS & IBA

- AMS Sample Preparation Facility
- Gas filled magnet (isobar separation)
- Ion implanters

ansto
Research Portal

Thu, 01 Sep 2016 10:23 AEST

Welcome

to ANSTO's Interim Research Portal.

This is your gateway to all of ANSTO's research facilities and experience.

Sign in

Email:

ams@ansto.gov.au

Password:

****

Login | Register

Forgot your password?

The 2017-1 Proposal Round for access to ANSTO's facilities and capabilities from January 2017 is now open. The deadline for proposals is 30 September 2016.

What is the ANSTO Interim Research Portal?

From 15 February 2016, this interim research portal will accept new proposals for access to facilities and capabilities at the Australian Nuclear Science and Technology Organisation (ANSTO), with the exclusion of the neutron-beam facilities at OPAL and the National Deuteration Facility.

A new ANSTO Research Portal will be available later this year and, for the first time, will provide one central location for the submission of proposals and subsequent experiments at ANSTO. The new ANSTO Research Portal is being designed to harmonise arrangements and processes across ANSTO to better support our user community.

ANSTO is one of Australia's largest public research organisations and custodian of much of our country's landmark and national research infrastructure, including the Open Pool Australian Lightwater (OPAL) multi-purpose research reactor, the Australian Synchrotron, the Centre for Accelerator Science and neutron beam instruments.

On average, ANSTO accommodates over 1800 visiting researchers from other Australian research organisations and international research centres each year to provide access to a wide range of world-class research facilities that support research into human health, our environment and innovation for industry.

As outlined above, this new interim research portal has been put in place for the first round of proposals for 2016. Proposals related to environment, archaeology, geoscience, material science and engineering, life sciences, biomedical and human health should be submitted through this interim portal.

Simply use your email address to register an account above.

You can then use the portal to submit proposals, edit proposals, add experimenters/collaborators and more.

If you encounter an issue with using this interim portal or have any other questions or queries, please contact Joseph Bevitt via the user office by email or by phone on (+61) 2 9717 7232.

Further changes and improvements will be made to the portal in time for the following proposal round later in 2016.

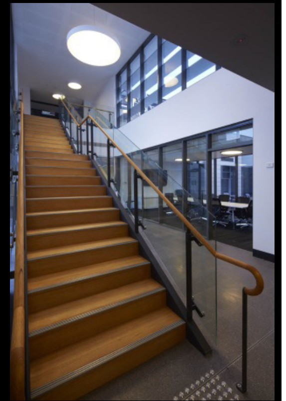
If your proposal is not related to the above facilities and capabilities, or is specifically related to OPAL and the neutron beam facilities, please use the Bragg Institute Customer Portal.

Round 2017-1
for access
1 Jan'17 to 30 Jun'17
closes on
15 September 2016

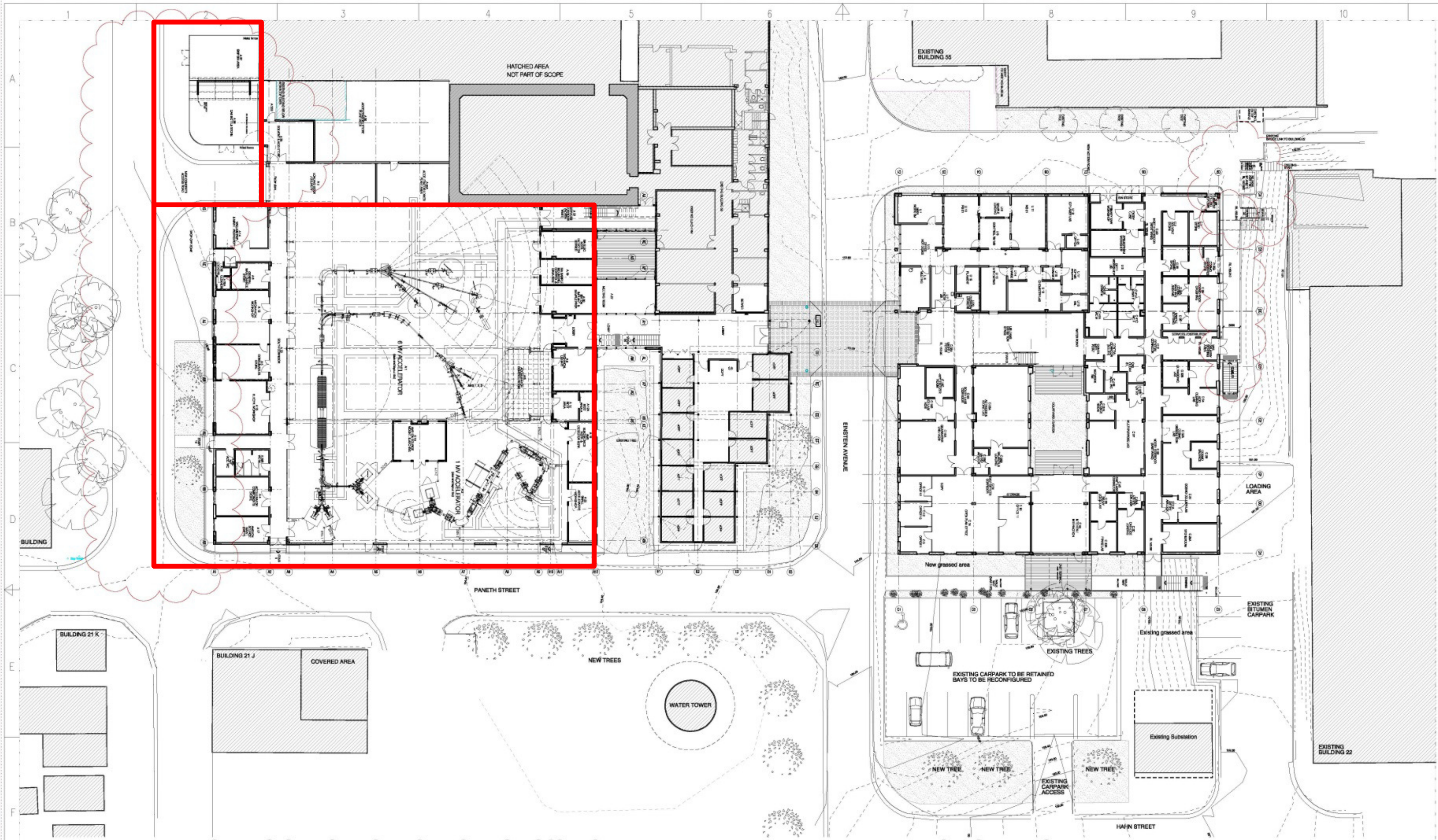
Round 2017-2
for access
1 Jul'17 to 31 Dec'17
closes on
15 March 2017

Bird building (B53)

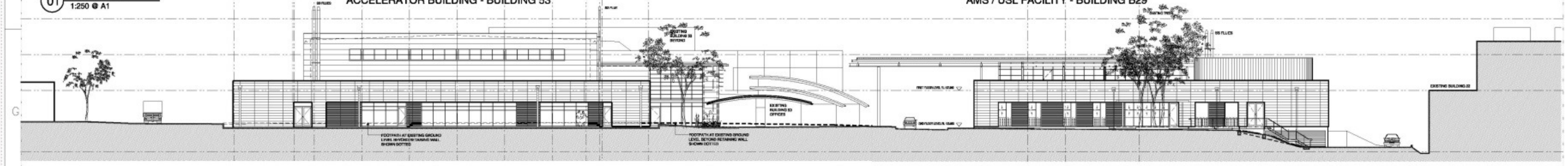





Home of ANTARES, SIRIUS & VEGA accelerators.



01 SITE PLAN
1:250 @ A1



02 SITE SECTION/ EAST ELEVATION
1:250 @ A1

GENERAL NOTES

CONTRACTOR TO READ ARCHITECTURAL DOCUMENTS IN CONJUNCTION WITH RELEVANT SERVICES DOCUMENTS.

CONTRACTOR TO IMMEDIATELY ADVISE ARCHITECT OF ANY CONFLICTS OR DISCREPANCIES ARISING ON SITE OR IN DOCUMENTATION PACKAGE. PRIOR TO COMMENCING WORKS OR INSTALLATION OF ITEMS.

STRUCTURAL MEMBERS ARE SHOWN INDICATIVE OF ARCHITECTURAL INTENT STEEL MEMBER SIZES, SPANS & LOCATIONS MUST BE VERIFIED BY STRUCTURAL ENGINEER.

SERVICE FIXTURES, FITTINGS AND RELEVANT INSTALLATION OF ELECTRICAL, HYDRAULIC, & MECHANICAL ARE SHOWN INDICATIVE FOR SET-OUT PURPOSES ONLY. REFER TO RELEVANT SERVICES DOCUMENTS FOR GREATER DETAIL OF SERVICES FIXTURES.

ENSURE SURFACE MOUNTED HYDRAULIC & GAS FIXTURES ARE, MOUNTED ON STAINLESS STEEL BACKING PLATE & ALL PENETRATIONS ARE FULLY SEALED, AIR TIGHT. REFER TO ARCHITECTURAL & SERVICES SPECIFICATION FOR SUITABLE SEALANT TYPE.
FINISH FACE OF PARTITION SET OUT FROM EXISTING GRID. GRID SETOUT TO CENTER OF EXISTING COLUMNS.

CONTRACTOR TO ENSURE THAT PREPARATION OF ALL SUBSTRATES PRIOR TO RECEIVING PROPOSED FINISHES ARE IN ACCORDANCE WITH MANUFACTURERS RECOMMENDATIONS SPECIFIC TO THE PROPOSED FINISH, FIXTURES & FITTINGS.

DO NOT LEAVE ANY WOOD/ PARTICLE OR FIBRE BASED MATERIALS EXPOSED TO LABORATORY ROOM ENVIRONMENT. ENSURE SURFACES ARE SEALED, IMPERVIOUS OR COATED WITH APPROVED COATING SYSTEMS.

SUPPLY INSTALL GROUPS

G1 - GROUP 1 - SUPPLY INSTALL BY BUILDER
G2 - GROUP 2 - SUPPLY BY CLIENT INSTALL BY BUILDER
G3 - GROUP 3 - SUPPLY AND INSTALL BY CLIENT

DETAIL TAG
CODE DESCRIPTION
XX DETAIL NUMBER
AXXXX PAGE NUMBER

SCOPE OF DRAWING
DENOTES AREA OUTSIDE OF DOCUMENTS SCOPE.

WINDOW TAG
W 0.24 EXTERNAL WINDOW
G 0.03 INTERNAL GLAZING

DOOR TAG
D.C34.02
D — DOOR
C — DEPARTMENT: ACC/ AMS/ USL
34 — ROOM NUMBER
02 — DOOR NUMBER
E — EXTERNAL
R — ROLLER DOOR

WALLS & PARTITION TYPES
P1 INTERNAL PARTITION TYPES REFER TO A8001- A8002 PARTITION TYPES.
FIRE RATED PARTITION TYPE. A8002
XX / A5XXX FOR EXTERNAL WALL TYPES, REFER TO WALL SECTIONS A5000 SERIES AND CORRESPONDING CONSTRUCTION DETAILS A5200 SERIES.

PRINTED 3/08/2011

95% PRE-TENDER REVIEW

CLIENT AGREEMENT
PRINT NAME : ______________________
SIGN NAME : ______________ DATE : / /

REV.	DATE	DESCRIPTION	EXECUTED	CHECKED	APPROVED
06	03/08/11	FOR SERVICES COORDINATION	CB	JR	MD
05	03/06/11	95% PRE-TENDER REVIEW	CB	JR	MD
04	20/05/11	FOR 95% TENDER SERVICES COORDINATION	CB	JR	MD
03	11/05/11	Issue for DG Consultant	CB	JR	MD
02	13/04/11	ISSUE FOR ACOUSTIC AND ACCESSIBILITY CONSULTANT	CB	JR	MD
01	10/03/2010	50 % DD ISSUE	CB	JR	MD

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DRG NO (DJRD): A 0010
SCALE: 1:250
JOB No.: 09 453
A1

TITLE:
ansto - CAS
SITE PLAN - Stage 1
EAST ELEVATION

DRAWN TO AS 1100 | DIMENSIONS IN MILLIMETRES | DO NOT SCALE

	NAME	DATE	SIGN
DRAWN		3/08/2011	
DRG. CKD			
DESIGNED.			
DESIGN CKD.			
APPROVED			

DRG.No.
REV 06

Bird building accelerators

B53 Accelerators

J. R. Bird Building

ANTARES
Operating

Duty Operator: Mihail IONESCU
Contact Details: 3301
Terminal Voltage: 2.01 MegaVolts
Access Conditions: Clear

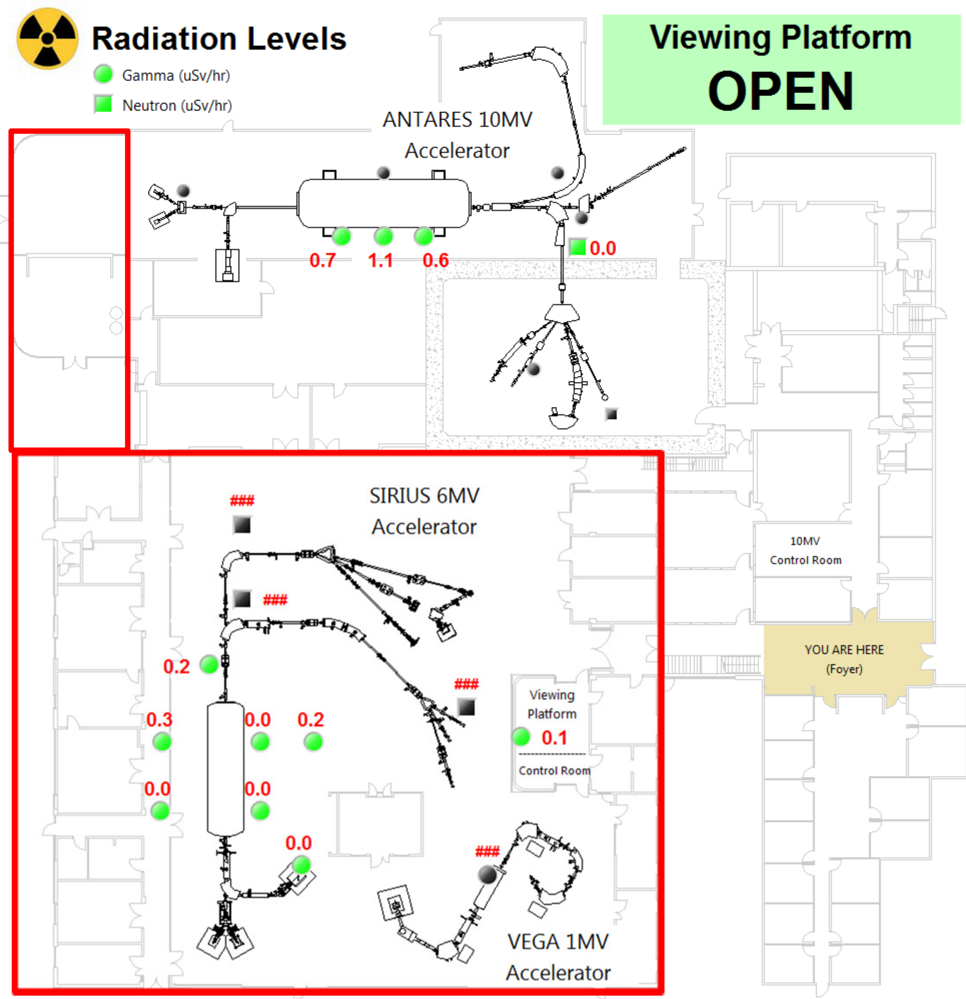
SIRIUS
Operating

Duty Operator: Klaus WILCKEN
Contact Details: 7560
Terminal Voltage: 4.50 MegaVolts
Access Conditions: Clear

VEGA
OFF

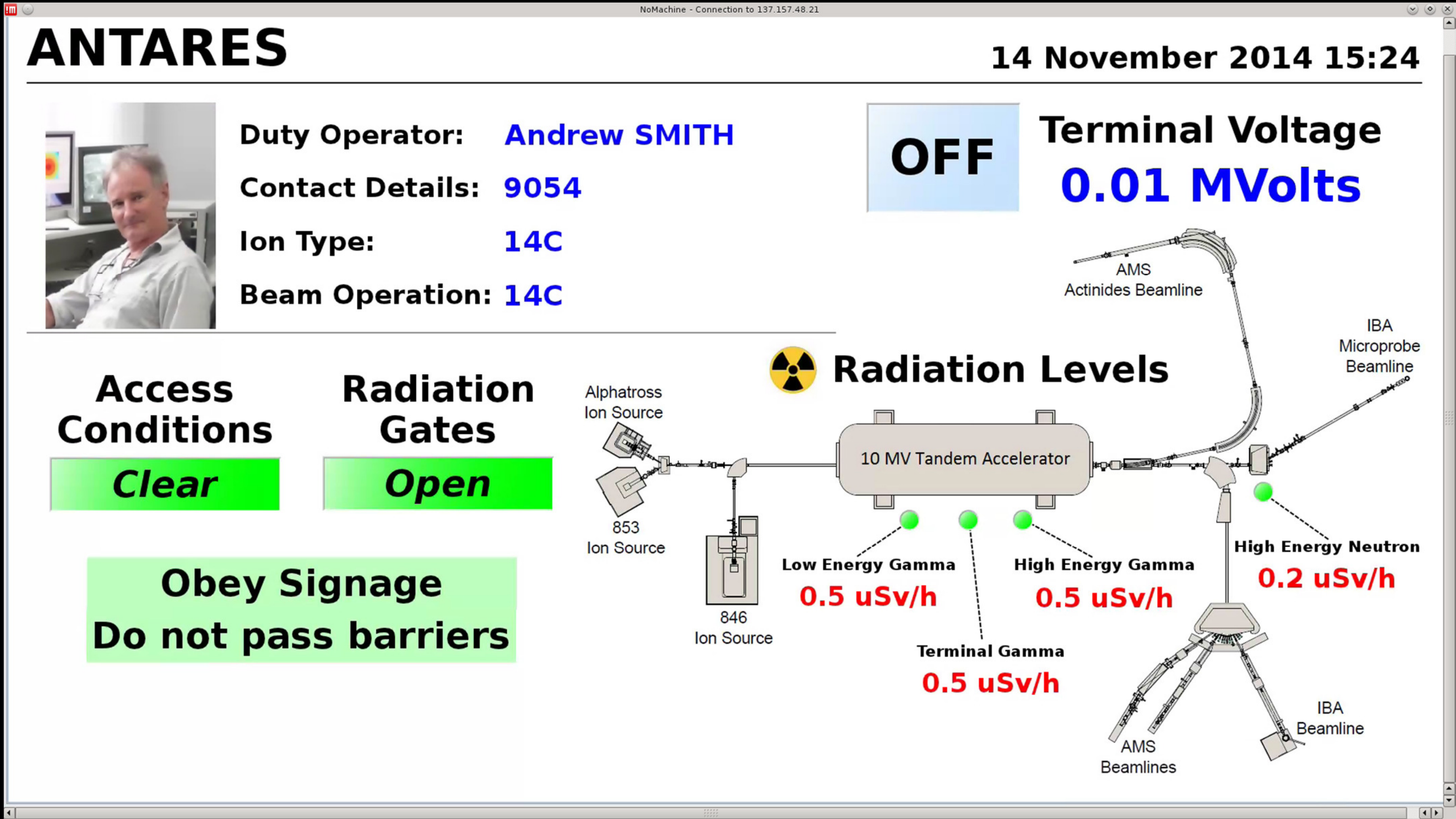
Duty Operator: Klaus WILCKEN
Contact Details: 7737
Terminal Voltage: 0.00 MegaVolts
Access Conditions: Clear

Obey Signage. Do not pass barriers



07 July 2015 11:41

ANTARES: 10MV (B53)



ANTARES: 10MV, HVEC, 1988, AMS & IBA

IBA beamlines:

Heavy ion microprobe

Elastic recoil detection (ERDA)

Neutron

Ion irradiation

AMS beamlines:

^{7}Be, ^{14}C, ^{26}Al, ^{36}Cl

^{10}Be

^{129}I & Actinide

Gas filled magnet

VEGA: 1MV, NEC, 2014, AMS

NEC 1 MV AMS system *(VEGA)*

Delivered November 2013

Specified for

1) ^{14}C

120 µA $^{12}C^-$, $^{14}C/^{12}C < 0.3\%$

0.04 pMC, $^{13}C/^{12}C < 0.1\%$

$^{14}C^{+1}$ at 0.5 MV

2) $^{233\text{-}238}U$ and $^{238\text{-}244}Pu$

M/ΔM ~ 500

ME/Q^2 =110 (+3, 1 MV)

LE & HE fast 8-mass bouncing

HE achromatic optics

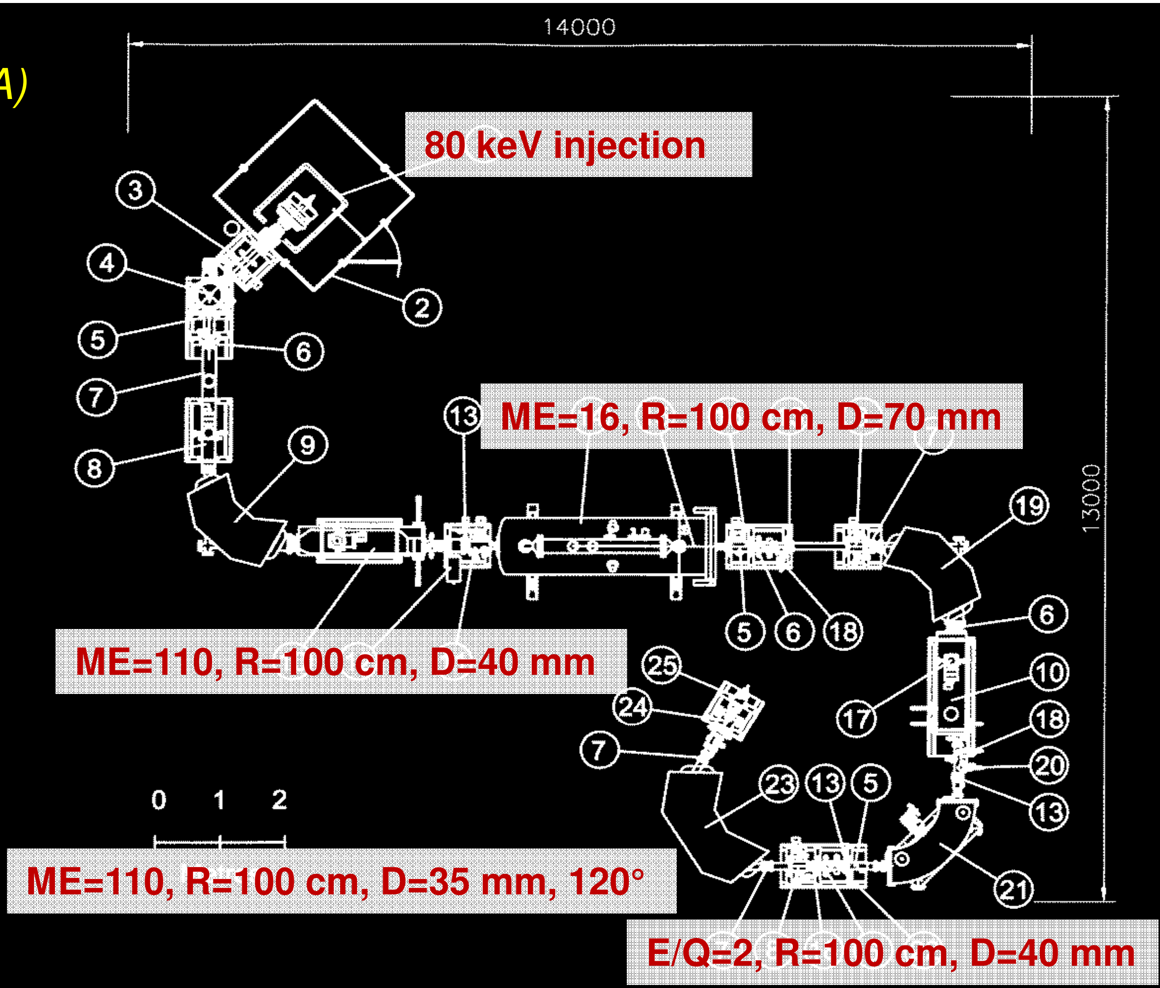
3-gas stripper

Pu^{3+} at 0.7MV

3) ^{10}Be

10 µA BeO^-, SiN foil

120° HE double focussing magnet, flared stripper canal



1. 134 MC-SNICS Ion Source
2. High voltage protection cage
3. Turbo Pump, Faraday Cup and Y Steerer
4. ±45° Electrostatic Spherical Analyser (ESA)
5. X-Y Steerer
6. Double Slit
7. Gap lens
8. Turbo Pumping Station
9. 90° Magnet
10. Multi-Faraday Cup
11. Turbo Pumping Station, Slit, Beam Profile Monitor (BPM) and Faraday cup
12. Einzel lens
13. Gate valve
14. 1MV Pelletron Accelerator
15. Electrocstatic Quadrupole
16. Turbo Pumping Station and BF
17. Turbo Pumping Station
18. Faraday Cup
19. 90° Magnet
20. Degrader Foil
21. 90° ESA
22. BPM
23. 120° Magnet
24. Multi-Faraday cup
25. Detector

SIRIUS: 6MV, NEC, 2015, AMS & IBA

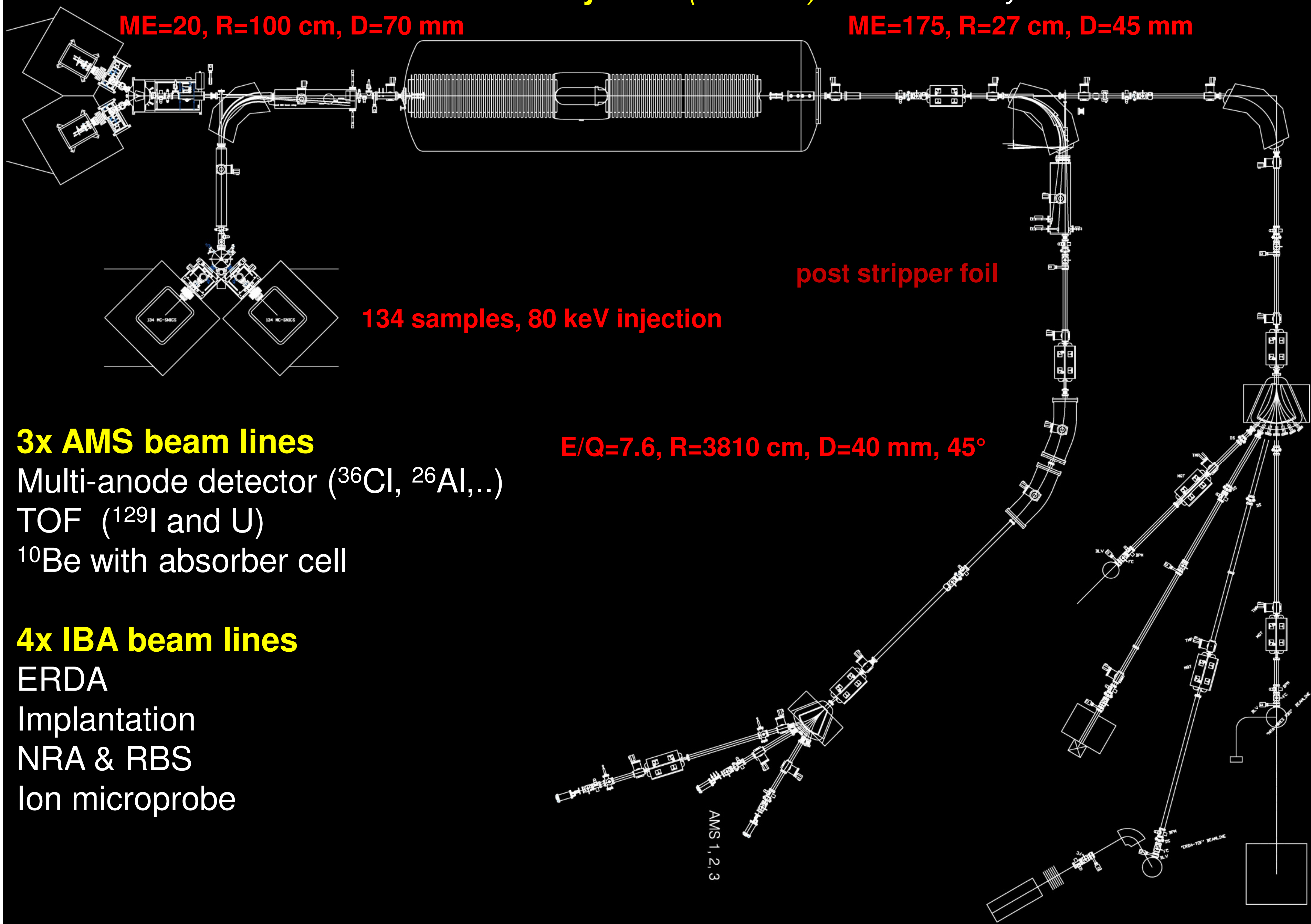
IBA beamlines:

Confocal heavy ion.
Surface engineering beamline.
Nuclear reaction analysis & channelling beamline.
Heavy ion implantation.

AMS beamlines:

Time of flight AMS beamline.
^{10}Be AMS beamline.
^{14}C, ^{36}Cl AMS beamline.

NEC 6 MV AMS + IBA system *(SIRIUS)* *Delivered July 2014*



3x AMS beam lines

Multi-anode detector (^{36}Cl, ^{26}Al,..)

TOF (^{129}I and U)

^{10}Be with absorber cell

4x IBA beam lines

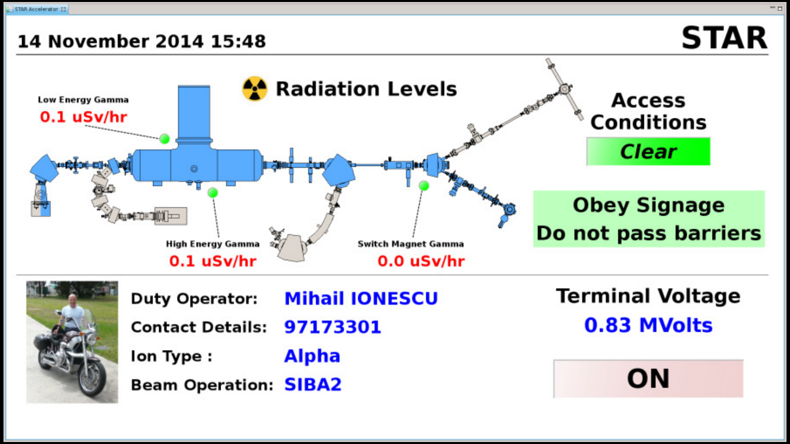
ERDA

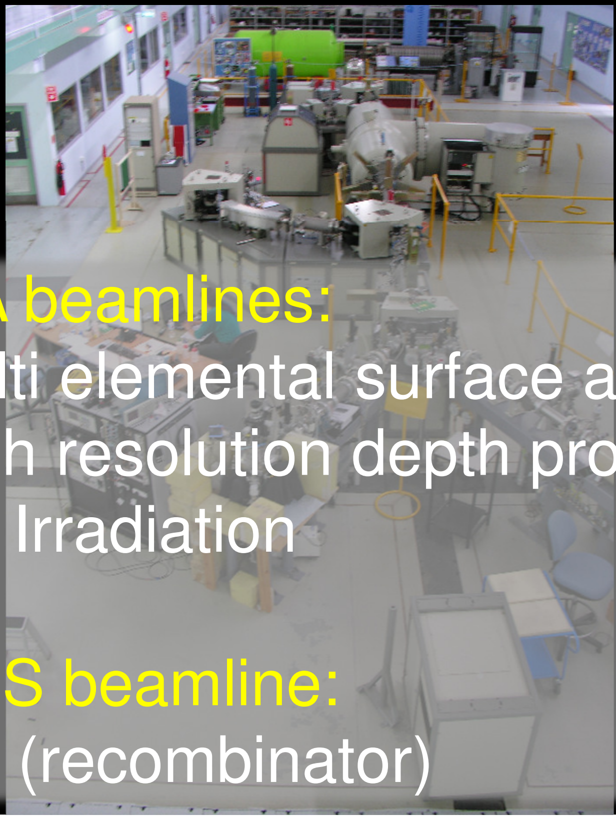
Implantation

NRA & RBS

Ion microprobe

STAR: 2MV (B22)





IBA beamlines:

Multi elemental surface analysis

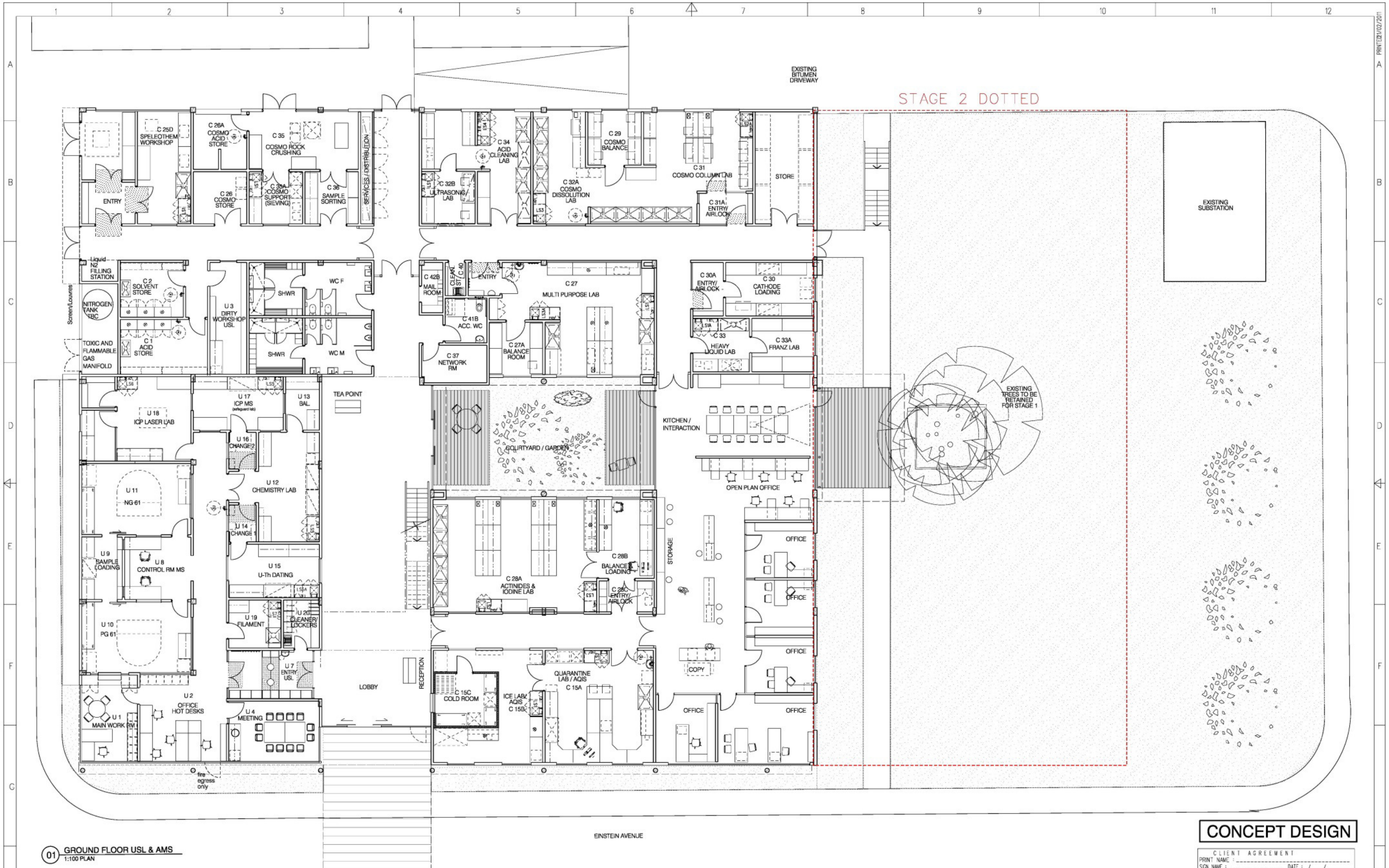
High resolution depth profiling

Ion Irradiation

AMS beamline:

^{14}C (recombinator)

Libby building (B29)



01 GROUND FLOOR USL & AMS
1:100 PLAN

CONCEPT DESIGN

CLIENT AGREEMENT
PRINT NAME : ______________________
SIGN NAME : ______________ DATE : / /

REV.	DATE	DESCRIPTION	EXECUTED	CHECKED	APPROVED
01	21/02/2010	Issue for CONCEPT ACCEPTANCE/ SIGN OFF	CB	MD	VM

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DRG NO (DJRD) A 1001
SCALE 1:100
JOB No. 09 453
A1

TITLE:
ansto - CAS
GROUND FLOOR PLAN
STAGE 1
AMS CHEMISTRY / USL

DRAWN TO AS 1100 | DIMENSIONS IN MILLIMETRES | DO NOT SCALE

	NAME	DATE	SIGN
DRAWN	CB/ MD/ VM	21/02/2011	
DRG. CKD			
DESIGNED.			
DESIGN CKD.			
APPROVED			

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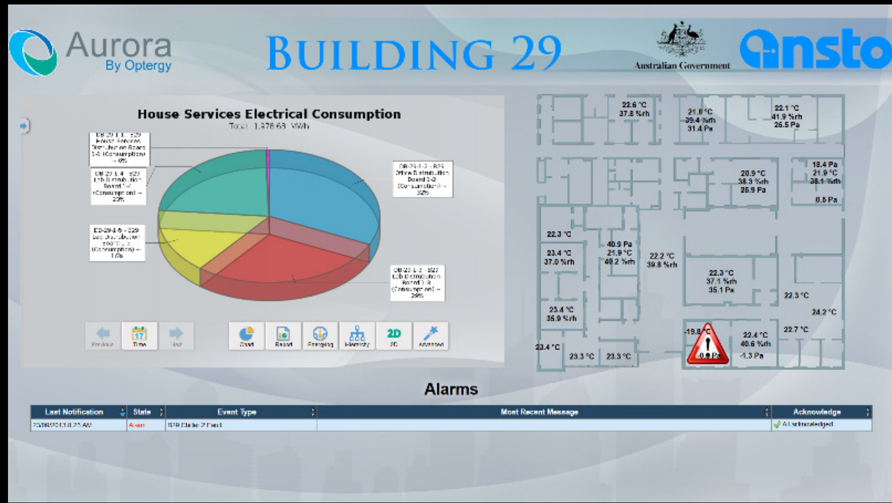
1

DRG.No.
REV 01

Libby building: AMS chemistry

- Quarantine laboratory
- Ice core lab: -20° freezer
- Actinides & iodine laboratory
- Speleothem laboratory
- Tree ring laboratory
- Multi-purpose laboratory
- Cosmogenic laboratory (rock crushing & sieving, heavy liquid & Franz separation, ultrasonic & acid)
- ^{14}C in situ dating laboratory
- Stable isotope laboratory

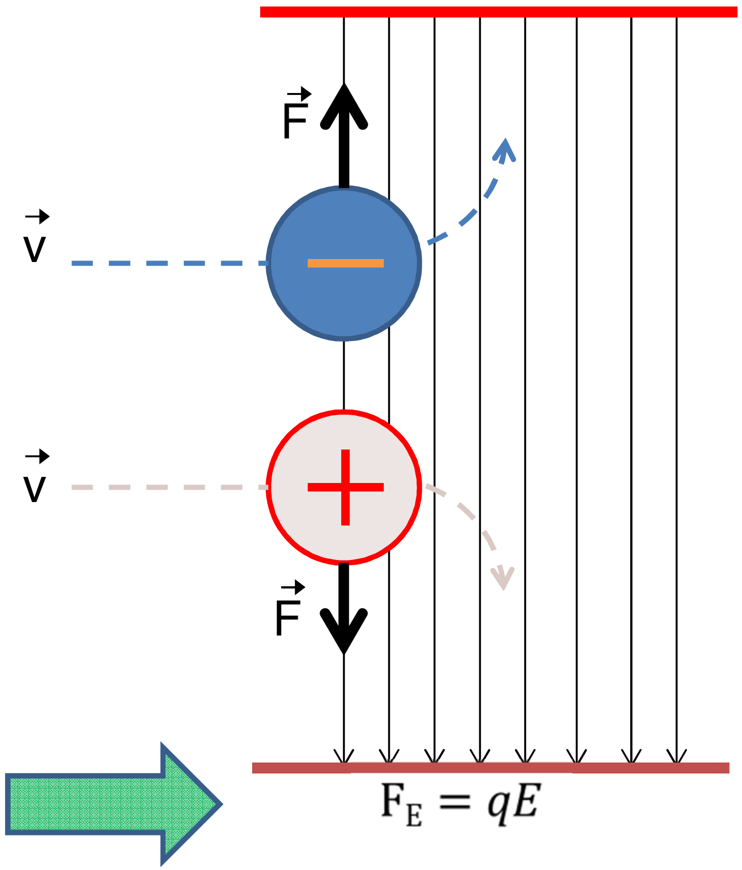


Stage 2: relocation of ^{14}C chemistry from B16.

What is a particle accelerator?

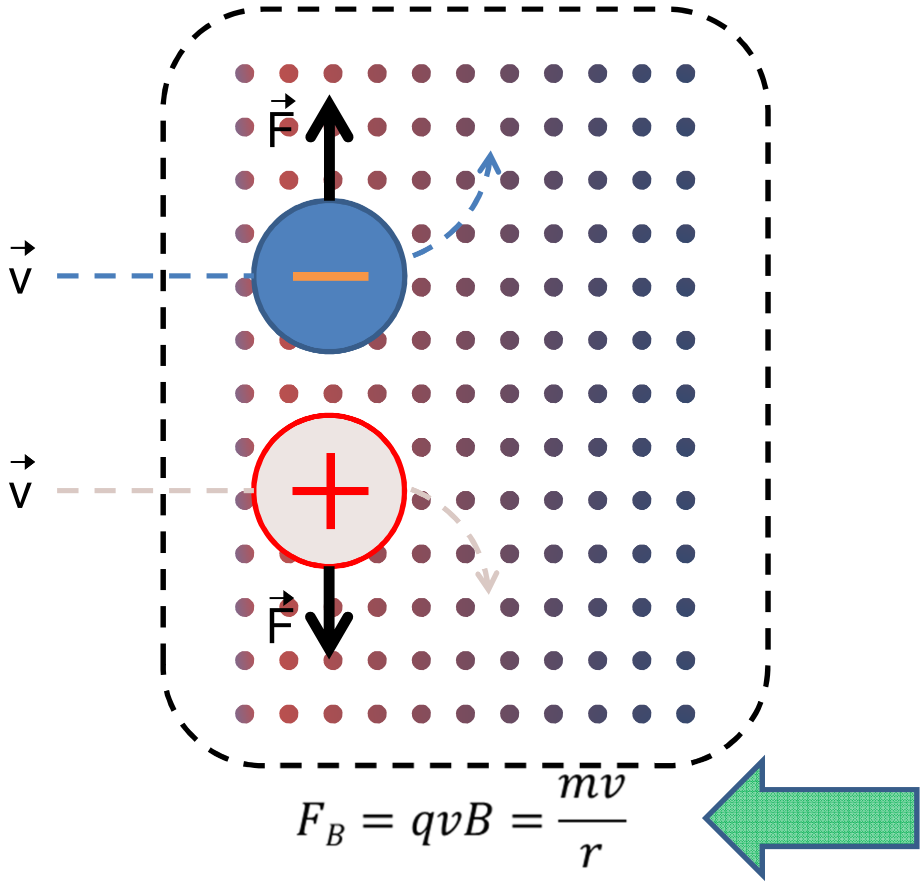
Particle accelerators are tools that produce ‘beams’ of charged particles (electrons, atoms or molecules) for identification or to study physical phenomena or interaction.

Electric Field



$$F_E = qE$$

Magnetic Field *(Field coming out of the page)*

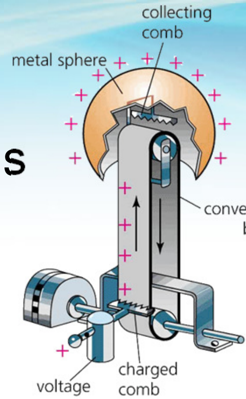


$$F_B = qvB = \frac{mv}{r}$$

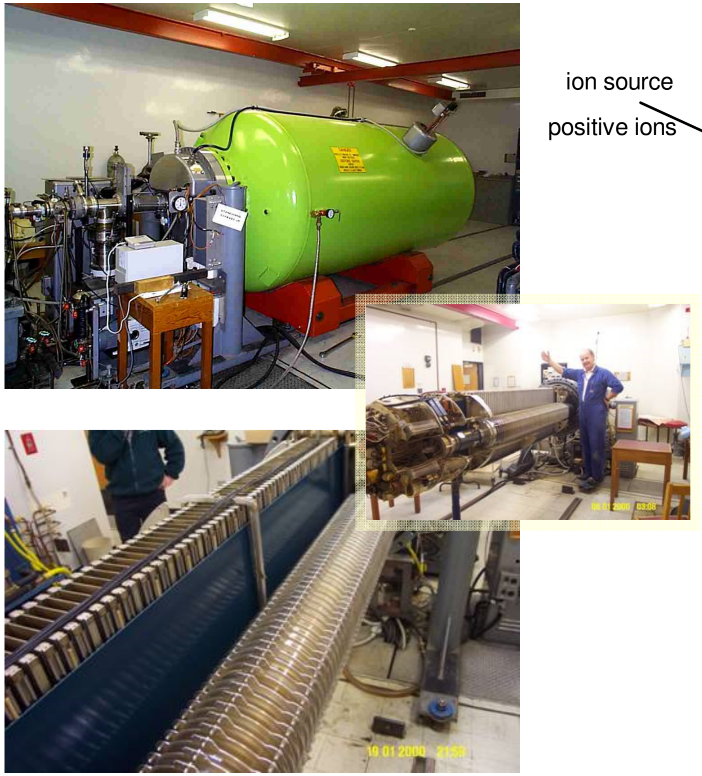
Electrostatic Linear Accelerators

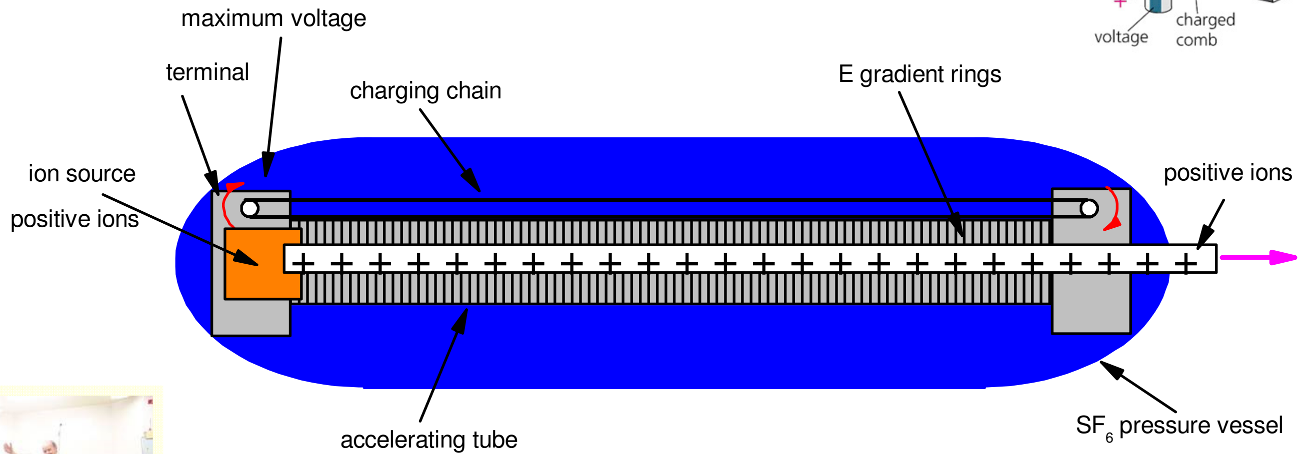
Purpose: to accelerate positive or negative ions to the desired energies

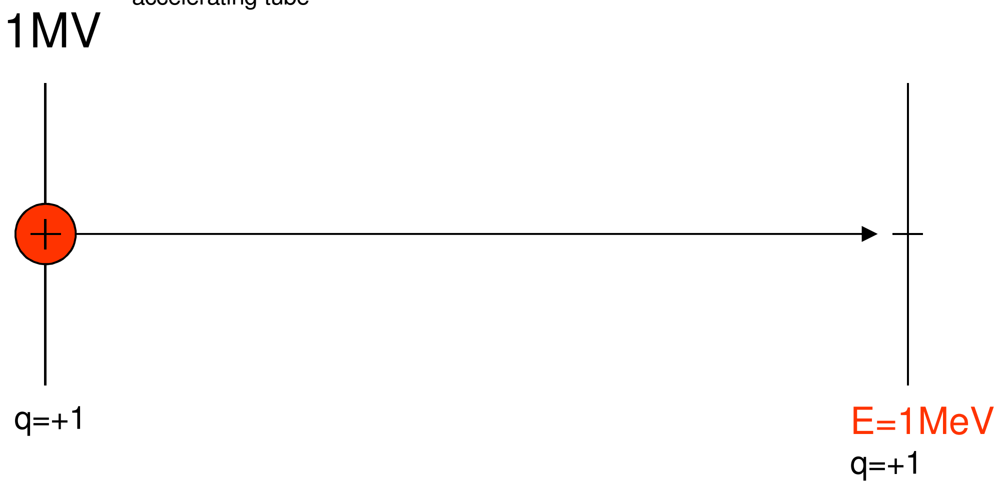
Types: single-ended and double-ended (tandem). Both produce DC Beams



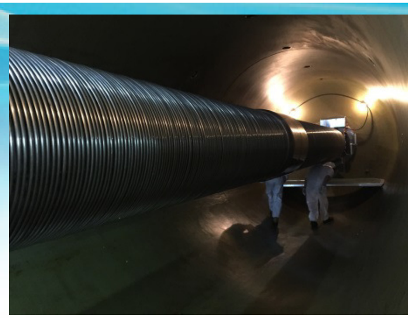
single-end accelerators: one acceleration stage

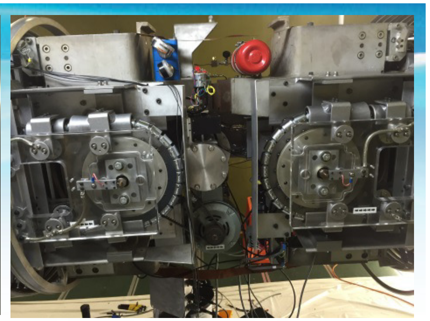


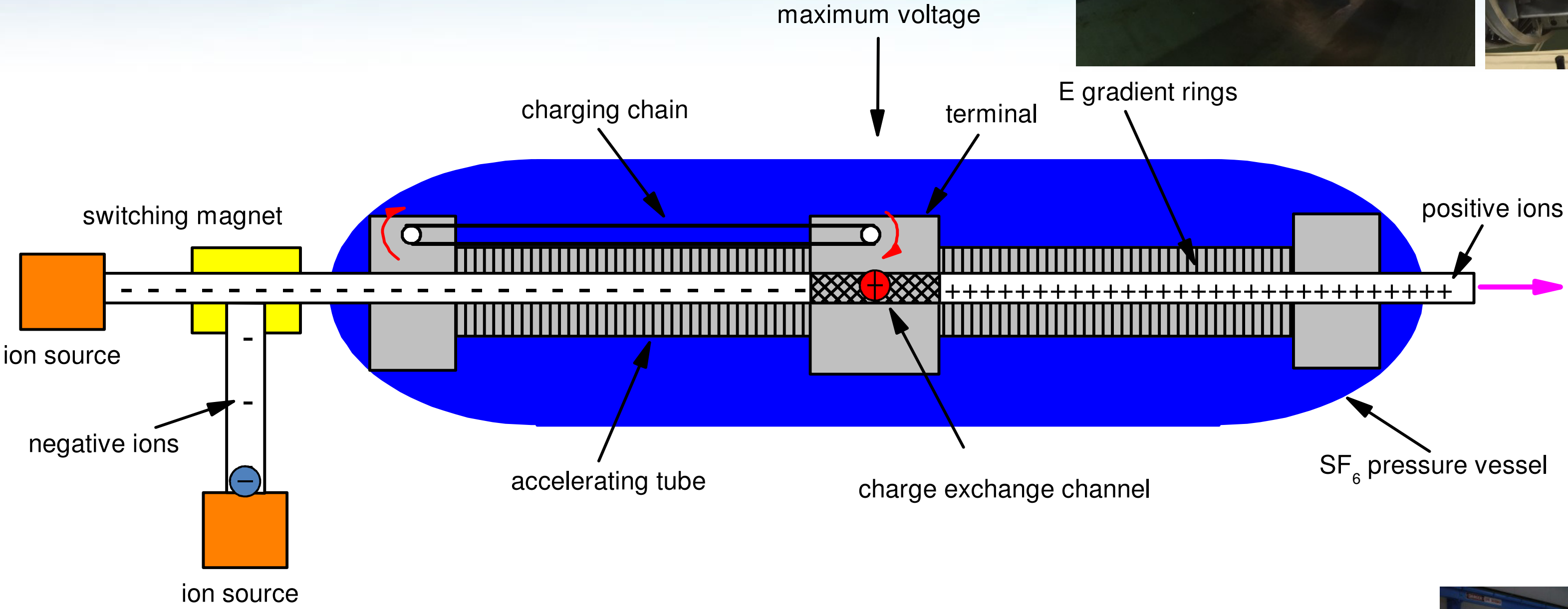


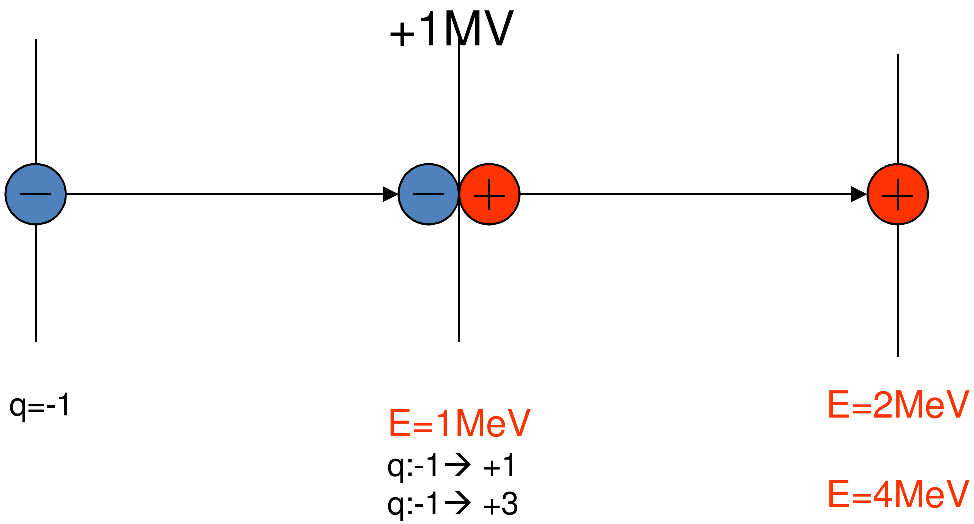


double-ended ‘tandem’ accelerators:
negative ion source, two acceleration stages



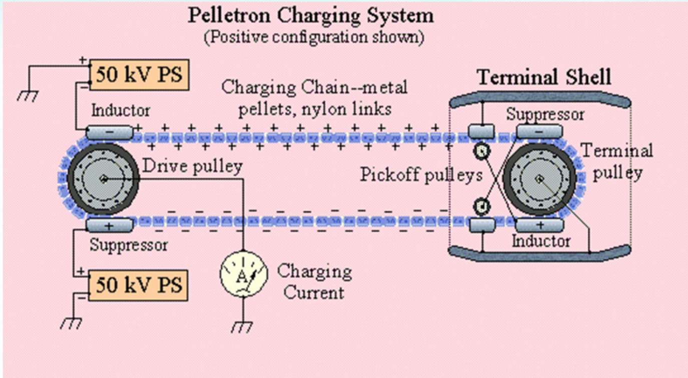






Accelerator Charging Systems

Pelletron charging system



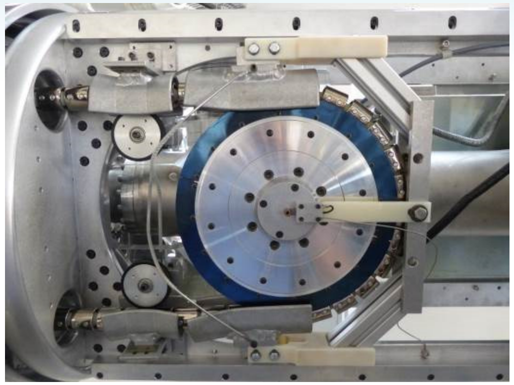
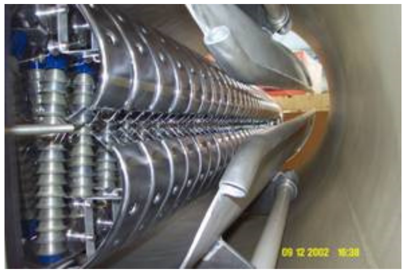
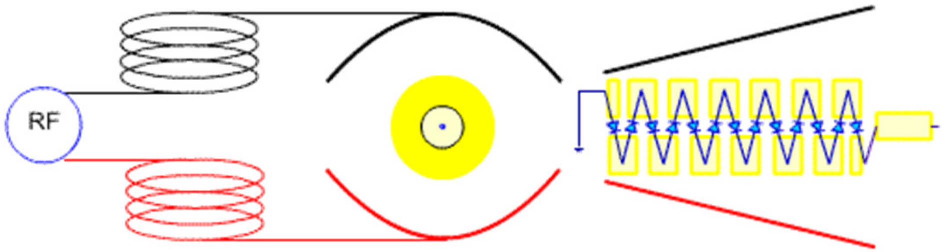


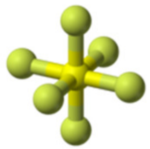
Diagram: http://www.pelletron.com/charging.htm



Tandetron solid-state charging system



insulating gas: sulphur hexafluoride (SF_6)



GWP 22,800 over 100 years!

Accelerator beam optical elements

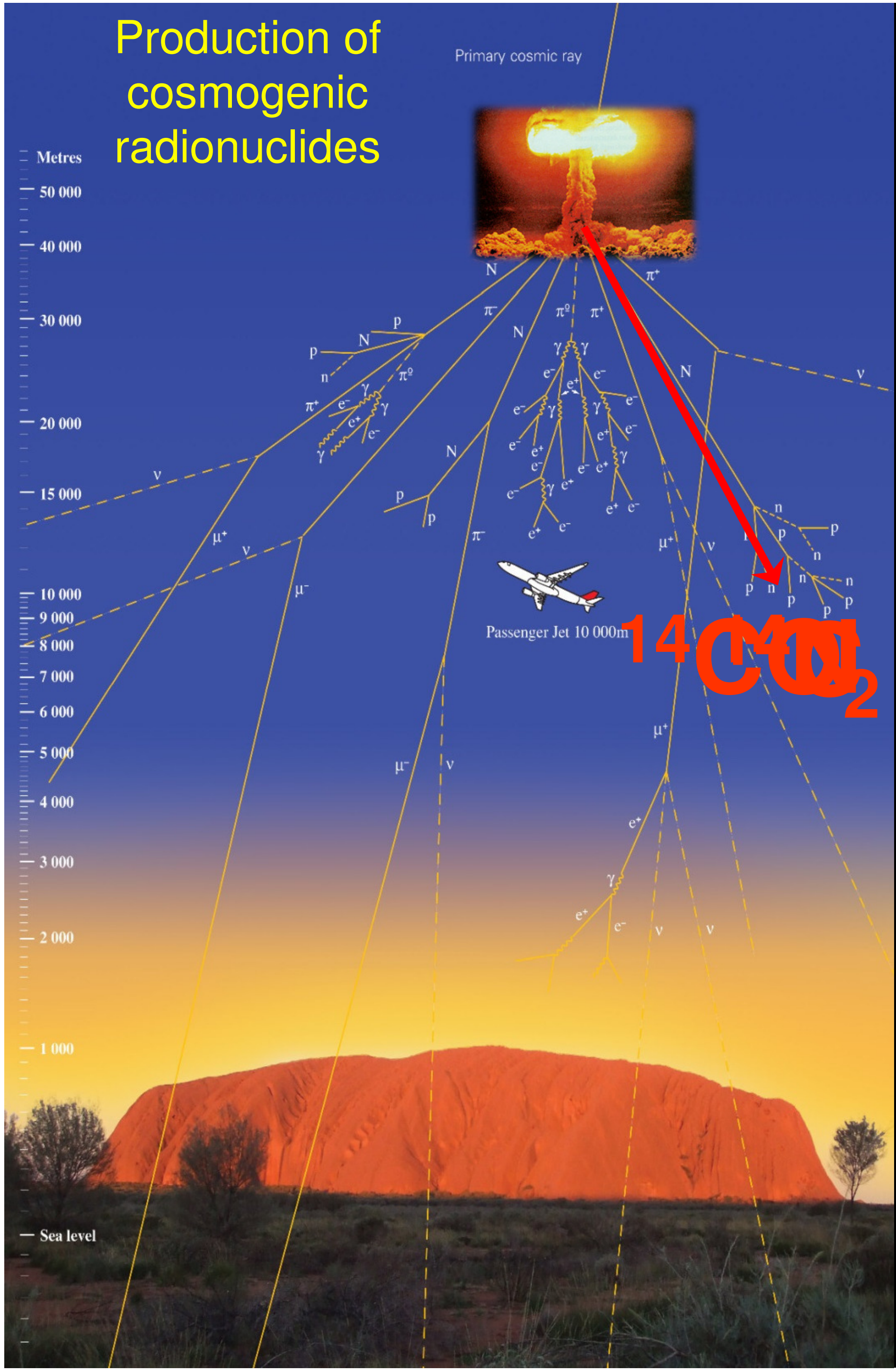
- Acceleration: acceleration tubes, gap lenses
- Mass selection: double-focusing dipole magnets
- Energy & charge selection: electrostatic analysers (cylindrical & spherical)
- Velocity selection: E×B filters (Wien filter)
- Focusing: Einzel lenses, quadrupoles (magnetic & electrostatic, doublets & triplets)
- Steering: electrostatic & magnetic deflectors
- Beam definition: slits & apertures
- Beam shape: beam profile monitors

- Vacuum pumps: need high vacuum (~ 10^{-6} Pa) to avoid collisions with background gas (causes charge and trajectory change)

What is *Accelerator Mass Spectrometry*?

- AMS (Accelerator Mass Spectrometry).

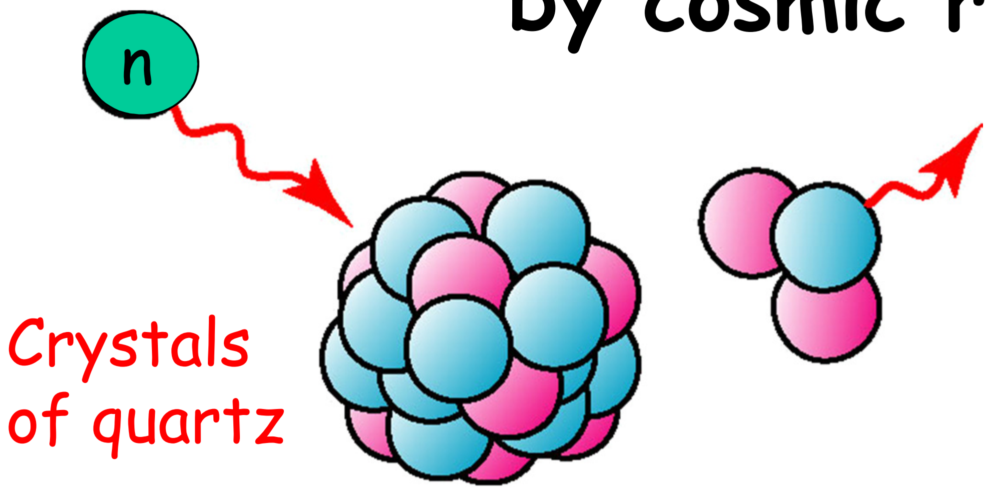
  AMS samples go into the ion source.
- An ultra-sensitive method for measuring isotopic ratios.
- AMS differs from other forms of mass spectrometry in that it accelerates ions to high kinetic energies before mass analysis.
- AMS is based on <u>atom counting</u> so it is inherently sensitive.
- AMS is typically used for isotopes that have intermediate half-lives and/or very low abundance: *often 'cosmogenic'.*
- Thus AMS finds many applications in Earth Sciences, archaeology, biomedicine, nuclear safeguards and nuclear forensics, to name but a few!



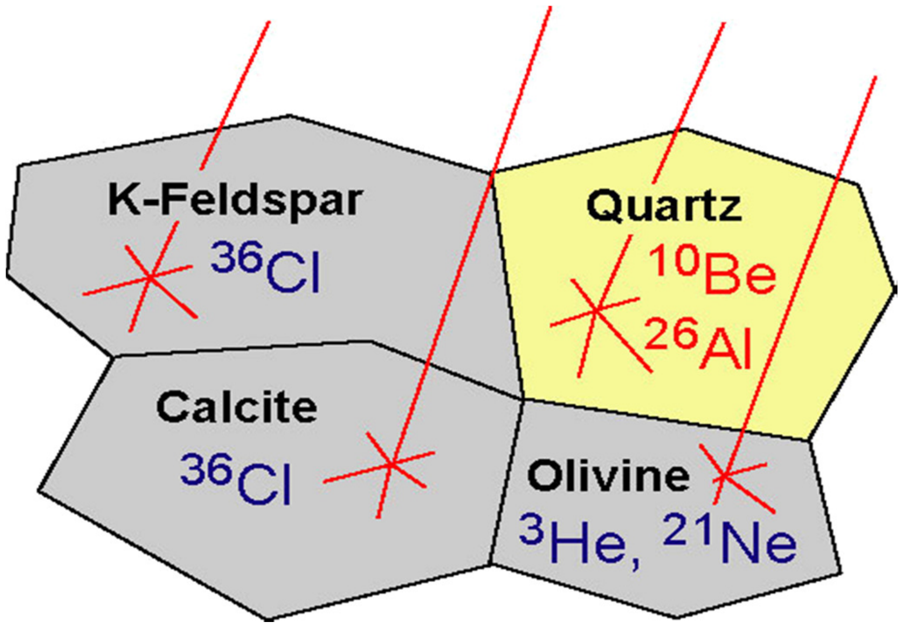
ANSTO AMS radionuclides

radioisotope	half-life (years)
'cosmogenic'	
^{7}Be	53.28 days
^{10}Be	1.39×10^{6}
^{14}C	5,730
^{26}Al	7.3×10^{5}
^{36}Cl	3.01×10^{5}
^{129}I	15.9×10^{6}
'primordial'	
^{235}U	7.04×10^{8}
^{236}U	2.342×10^{7}
'anthropogenic'	
^{239}Pu	2.410×10^{4}
^{240}Pu	6.56×10^{3}
^{242}Pu (as 'spike')	3.75×10^{5}

Cosmogenic isotope production by cosmic rays in rocks



Some target minerals



^{28}Si (n,p2n) ^{26}Al

^{16}O (n,4p3n) ^{10}Be

AMS isotopes & applications

- Common AMS isotopes (half-lives):

carbon-14 (5730 a), beryllium-10 (1.39 Ma), chlorine-36 (301 ka), aluminium-26 (720 ka), iodine-129 (15 Ma), calcium-41 (103 ka), actinides (various)

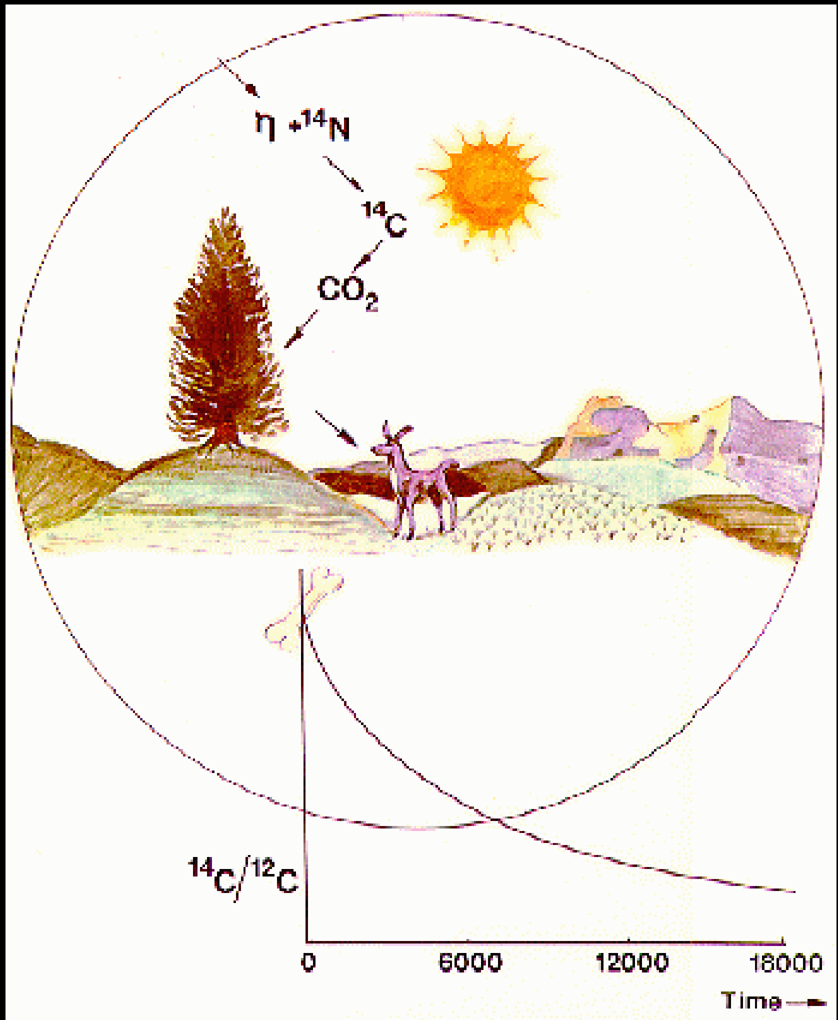
- Applications (incomplete list!):

archaeology, exposure-age dating, landscape evolution & catastrophic events, global climate change, pollution, biomedicine, oceanography, hydrology, extra-terrestrial material, nuclear physics, nuclear safeguards, materials analysis, …..

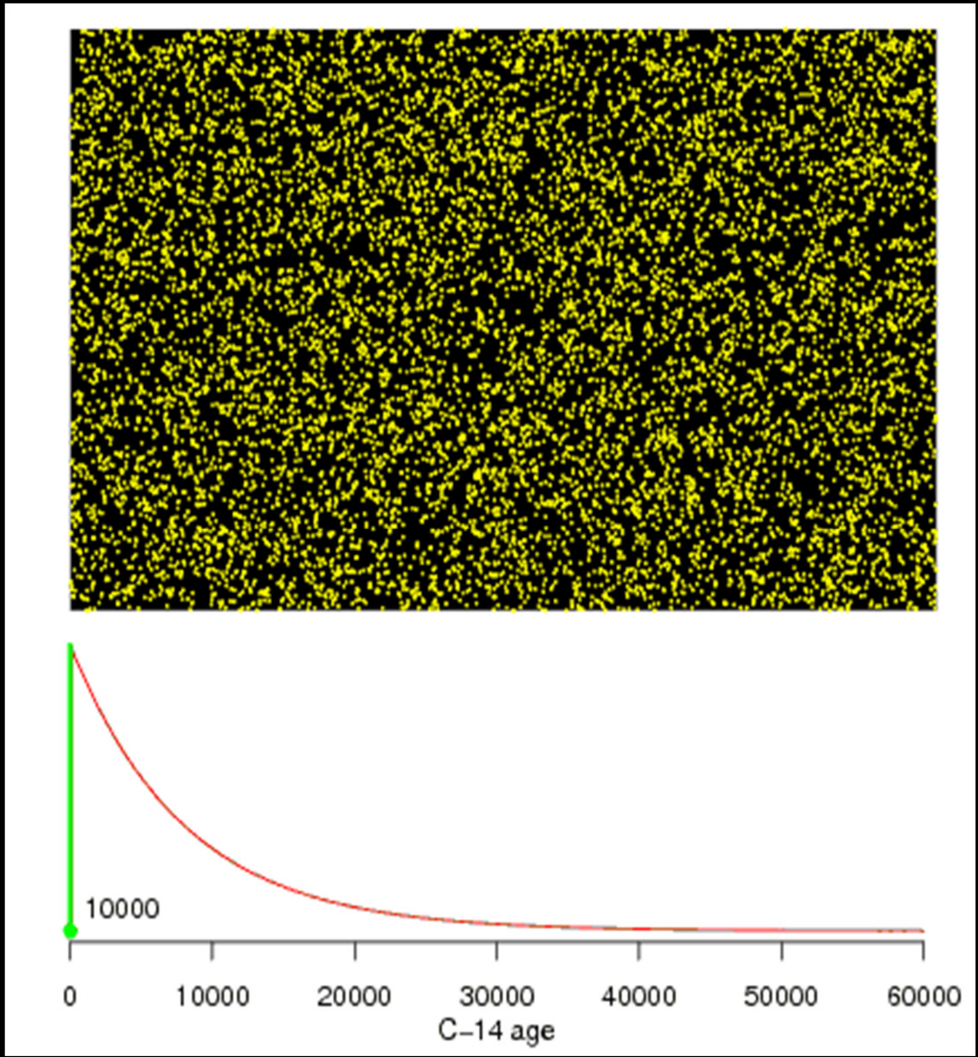
- Other AMS isotopes (half-lives, applications):

tritium (12.5 a, biomed), beryllium-7 (53 days, tracing), silicon-32 (~160a, dating, biomed), manganese-53 (3.8 Ma, meteorites, supernova, biomed, nuclear waste), iron-60 (1.5 Ma, supernova), nickel-63 (100 a, fast neutron dosimetry), selenium-79 (1.1 Ma, biomed), strongtium-90 (28.5 a, nuclear safeguards)

Principle of radiocarbon dating



- ^{14}C or radiocarbon produced by neutron capture on ^{14}N.
- Photosynthesis: living organisms are in equilibrium with the atmosphere.
- The radiocarbon clock starts on death: ^{14}C uptake ceases.
- Radiocarbon dating method: Willard F. Libby, Chicago 1950.
- Initially *Radiometric* and then *accelerator mass spectrometry*.



credit: M. Blaauw 2007,
chrono.qub.ac.uk/blaauw

- Black square is carbon, mostly ^{12}C (99%) and ^{13}C (1%).
- Yellow dots are ^{14}C atoms, initially 10^4 atoms.
- ^{14}C atoms are radioactive and disintegrate with a half-life of 5,730 years.
- When? It cannot be predicted for a given atom.
- Dating old samples is difficult: few ^{14}C atoms remain.
- Modern natural carbon contains ~ 50 million per mg.

How do we actually do ^{14}C AMS?

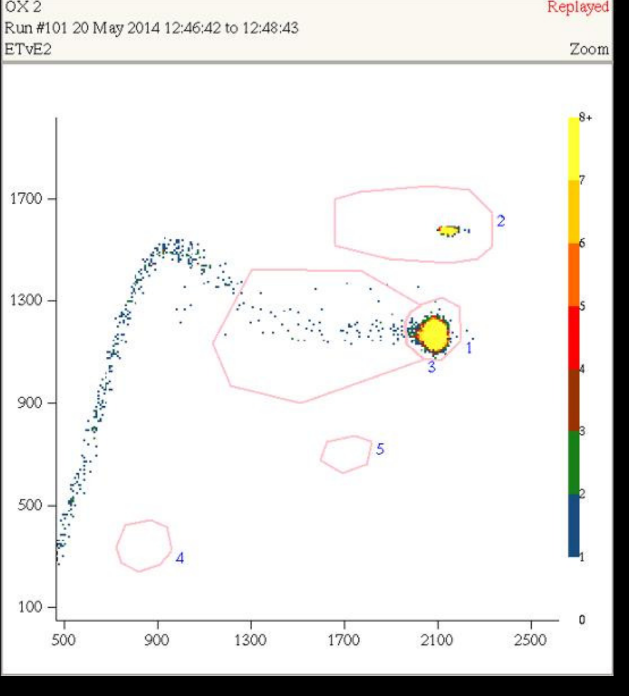
- Aim: to determine the $^{14}C/^{12}C$ ratio ('activity') for a sample.

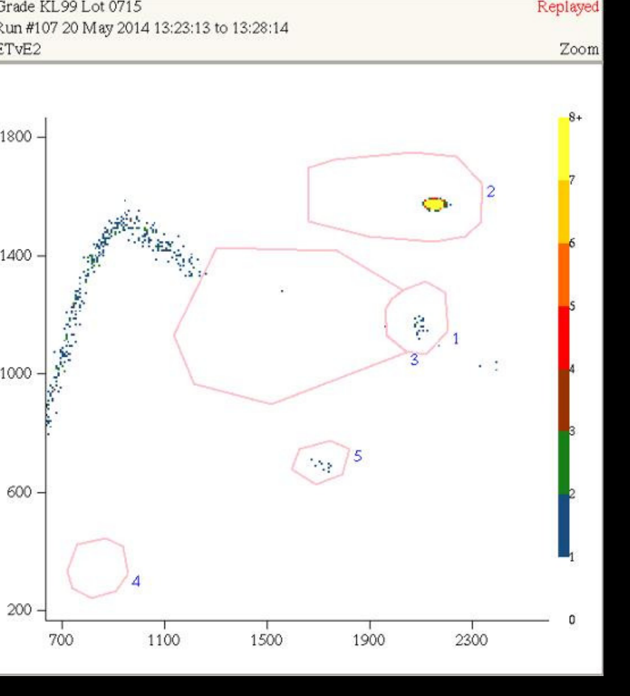
- The sample must firstly be physically and chemically purified to isolate the carbon: *this can be complex & time consuming!*
- The sample carbon is ionised in a negative ion source and beams of $^{12}C^{-}$, $^{13}C^{-}$ and $^{14}C^{-}$ are produced.
- These beams are accelerated in a tandem accelerator and are stripped to positive beams at the central stripper then further accelerated.

- ANTARES: terminal voltage 5.2 MV, $^{14}C^{4+}$ @ 26 MeV,
  isotope bouncing
- STAR: terminal voltage 2 MV, $^{14}C^{3+}$ @ 8 MeV,
  recombinator

detection

- Stable ^{12}C and ^{13}C beams are measured by charge digitisation.
- Rare radioactive ^{14}C events counted in an ionisation detector.
- Unknowns are measured against ^{14}C standards and ^{14}C-depleted material.





Why use tandem AMS ^{14}C measurement?

negative ions: elimination of ^{14}N isobar

charge exchange: destruction of $^{12}CH_2$ & ^{13}CH in terminal

ionisation detector: E,M,Z $\Rightarrow$ atom counting!

features:

ultra-small samples ~ 0.1 mg: at ANSTO ~5µg

rapid measurement ~ 20 min

sensitivity: 1 in 10^{16}: atom counting!

accuracy ~ 0.3%, background ~ 50 ka

Micro-sample (~5-100µgC) applications

climate change

- CO, CO_2 & CH_4 in ice sheets [major driver]
- particulate matter in ice sheets
- aerosol fractions for source discrimination/apportionment: elemental carbon, organic tracers & toxic compounds

chronology, archaeometry

- Palynomorphs: pollen, microforamifera, phytoliths, diatoms
- organic fractions from archaeological material (mummies, cooking vessels, residues…)

biomedical

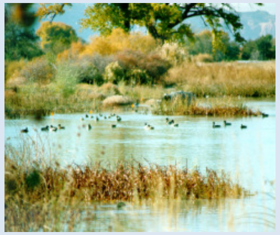
- DNA (eg for brain/neuron cell age), specific compounds

Preparative gas chromatography

CO, CO_2 & CH_4 from polar ice sheets

Sources of methane

Natural processes



Wetlands

Termites

Wild animals

Oceans

Geologic

Wildfires

Human activity

Rice cultivation

Landfills

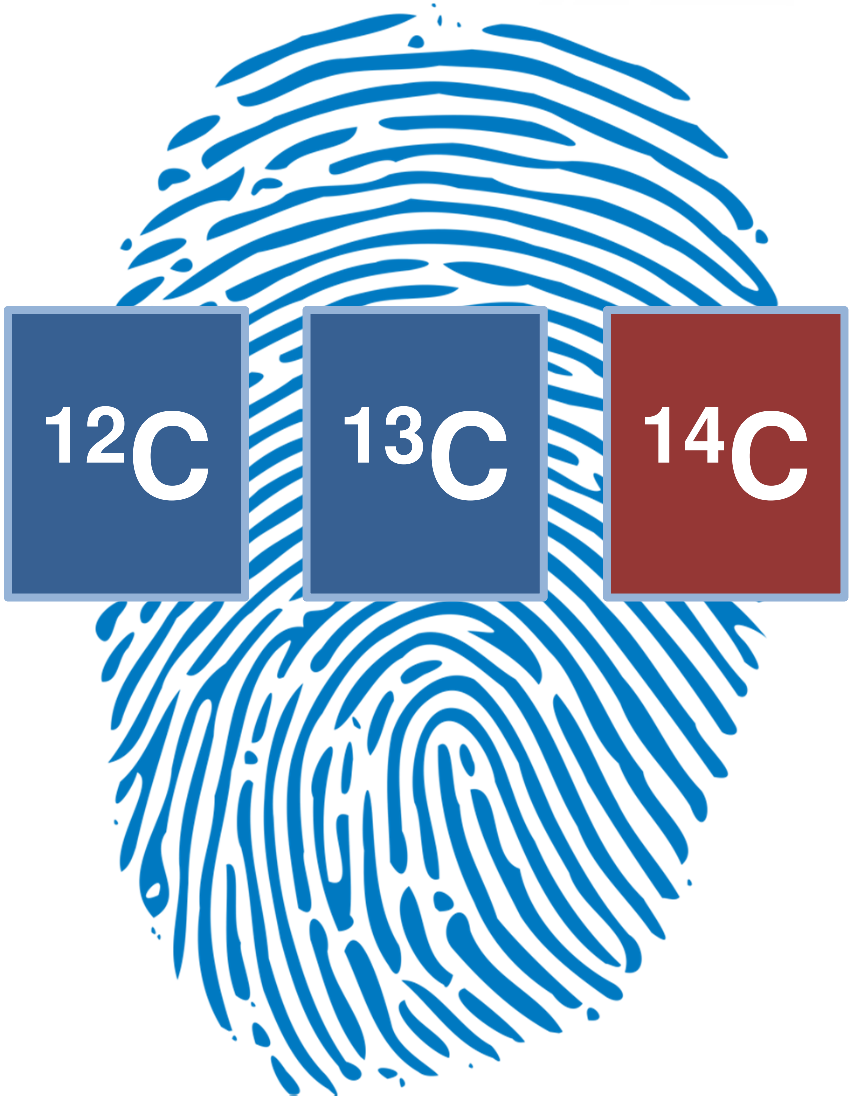
Wastewater

Livestock

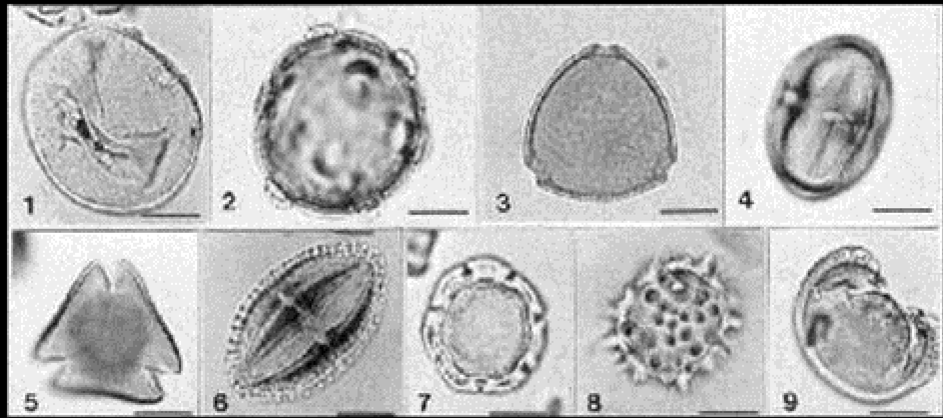
Gas & petroleum

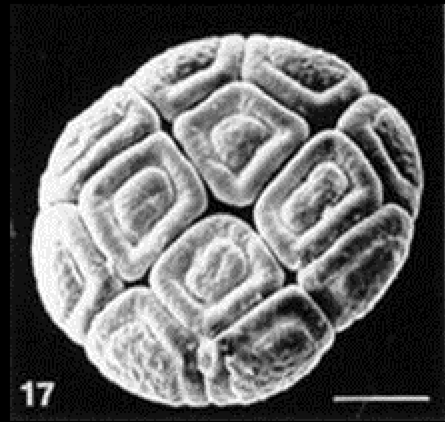
Coal mining

Identifying origin of methane

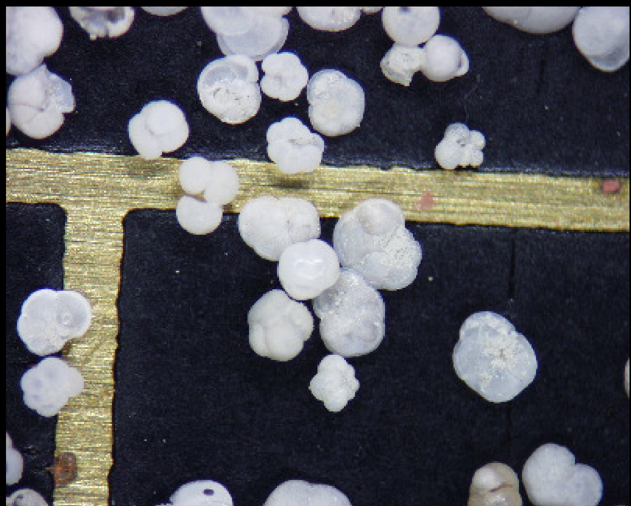


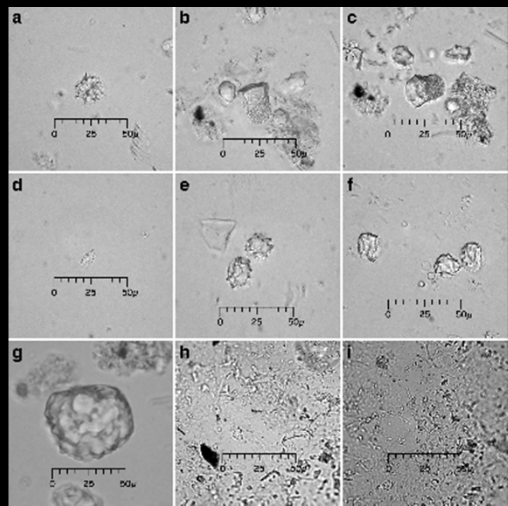
Palynomorphs

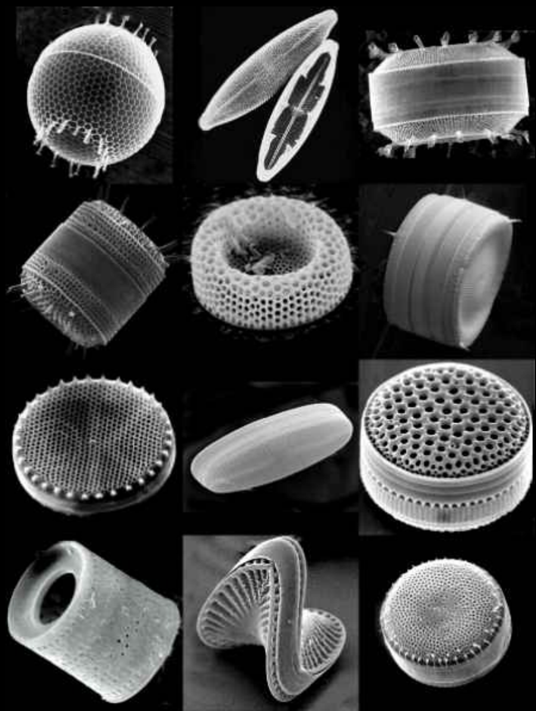




Pollen from flowering plants and a cone-bearing plant (pine). [All Scale bars = 10µm.]

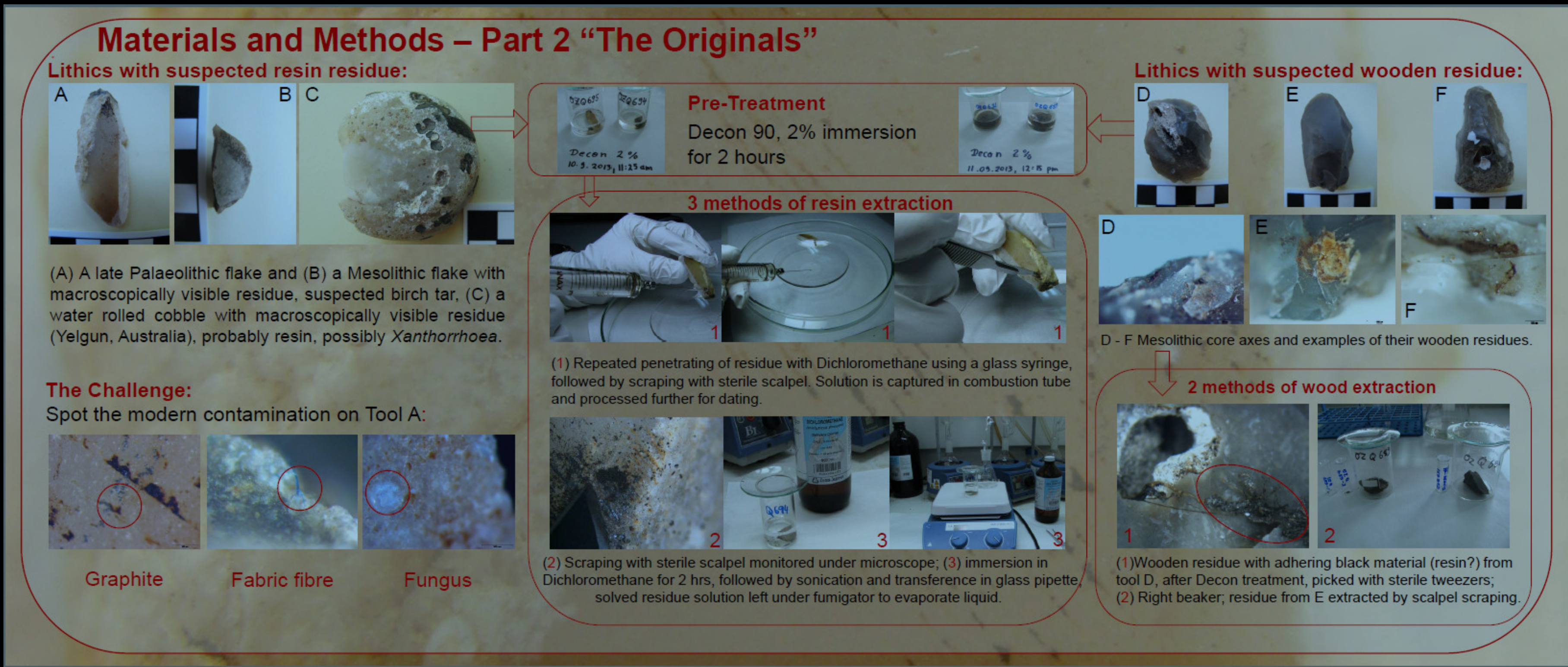






L-R: foramifera, phytoliths, diatoms.

artefact wear & use residues

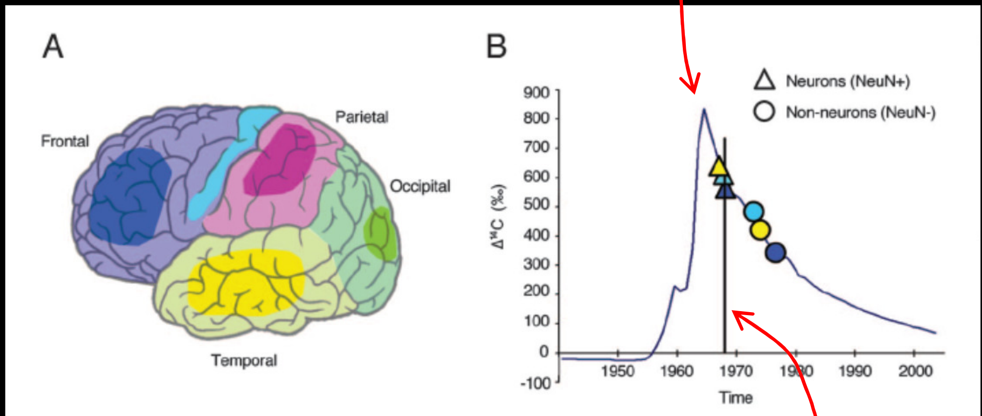


Radiocarbon ‘dating’ human cortical neurons

How old are the neurons in the cerebral cortex of the human brain?
ANSTO collaboration with the Medical Nobel and Karolinska Institutes, Sweden

- ANSTO’s international reputation for *microgram ^{14}C dating* – DNA samples at 10 μg
- Exploits atmospheric doubling of ^{14}C due to nuclear weapons testing in the 60’s

^{14}C bomb pulse



birth year

Adult cortical neurons have ^{14}C levels corresponding to time of birth suggesting an absence of cortical neurogenesis

Neocortical neurogenesis in humans is restricted to development

Ratan D. Bhardwaj*†, Maurice A. Curtis†‡, Kirsty L. Spalding*, Bruce A. Buchholz§, David Fink¶, Thomas Björk-Eriksson‖, Claes Nordborg**, Fred H. Gage††, Henrik Druid‡‡, Peter S. Eriksson‡§§, and Jonas Frisén*§§

12564–12568 | PNAS | August 15, 2006 | vol. 103 | no. 33

NEUROSCIENCE

No More Cortical Neurons for You

Pasko Rakic

18 AUGUST 2006 VOL 313 SCIENCE www.sciencemag.org

What is *Ion Beam Analysis*?

- IBA (ion beam analysis).

  IBA samples go into the end stations.

- Ion Beam Irradiation:

Chemistry, Defects, Damage, Neutron Production

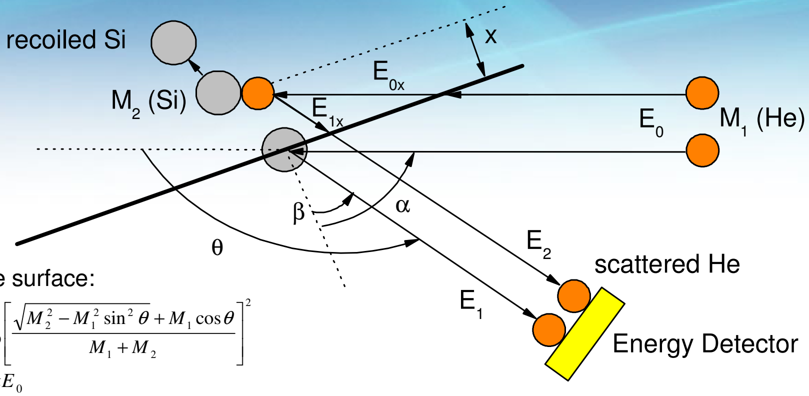
- Ion Beam Characterization:

Rutherford Backscattering Spectroscopy (RBS, C-RBS); Particle Induced X-ray Emission (PIXE); Elastic Recoil Detection Analysis (ERDA); Nuclear Reaction Analysis (NRA); Heavy Ion Micro-probe (HIMP).

IBA Characterisation Techniques

Analytical Technique	Typical Applications	Elements Detected	Sensitivity	Depth Resolution	Analysis Depth
RBS	Surface and thin film composition and thickness.	Li - U	Best for heavy elements on light element substrate (eg Cu on Si) typical 10% (Li) - 0.001% (U)	5-20 nm	up to 1 mm
PIXE	Trace element composition of particulates and bulk materials.	Si-U	Optimum near Fe (1ppm) elemental sensitivities range from 1 - 100ppm	typical proton range 20- 50 microns	up to 1 mm
PIGE	Trace light element composition of particulates and bulk materials.	Li-Al	Element dependent, typical < 1 ppm for F < 40 ppm for Na < 40 ppm for Al	-	up to 1 mm
NRA	Isotopic tracing and profiling in materials, surfaces and interfaces.	H-Si	Element dependent, typically in range 1 - 100 ppm	5-20 nm	up to 1 mm
PESA	Hydrogen in thin polymers; polymer interdiffusion, hydrogen in solar cells.	H, D	> 0.1%	10-20 nm	up to 1 mm
ERD & RToF	Elemental composition and structure of near surface regions, interfaces, thin films.	H-U	> 0.1 %	10-20 nm	up to 1 mm
µPIXE	Trace element mapping in biological, environmental and geological samples.	Si-U	> 100 ppm	-	up to 3 µm
µERDA	Elemental mapping and depth profiling of hard surfaces.	H-U	> 0.1 %	> 50 nm	up to 20 µm
IBIC	Charge collection mapping in electronic devices and detectors.				up to 1 µm

Rutherford Backscattering



At the surface:

$$E_1 = E_0 \left[\frac{\sqrt{M_2^2 - M_1^2 \sin^2\theta} + M_1 \cos\theta}{M_1 + M_2} \right]^2$$

$$E_1 = kE_0$$

At depth x:

$$E_{0x} = E_0 - \frac{x}{\cos\alpha} \frac{dE_0}{dx}$$

$$E_{1x} = kE_{0x}$$

$$E_2 = E_{1x} - \frac{x}{\cos\beta} \frac{dE_{1x}}{dx}$$

$$N[at/cm^2] = \frac{Y[cts]\cos\alpha}{N_i \Omega \frac{d\sigma}{d\Omega}}$$

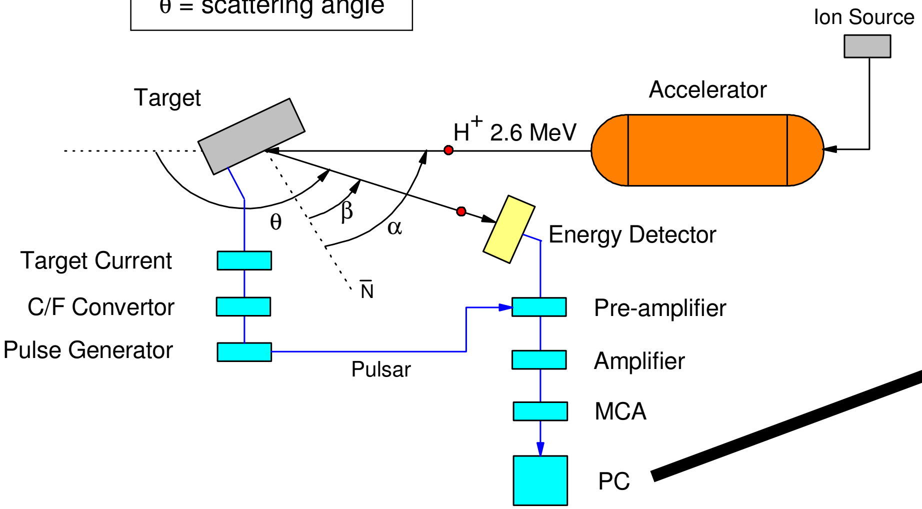
$$\frac{d\sigma}{d\Omega} = \frac{[Z_1 Z_2 e^2 (M_1 + M_2)]^2}{4E_0^2 M_2^2 \cos\theta}$$

N_i - number of ions incident on sample

Ω – detector solid angle

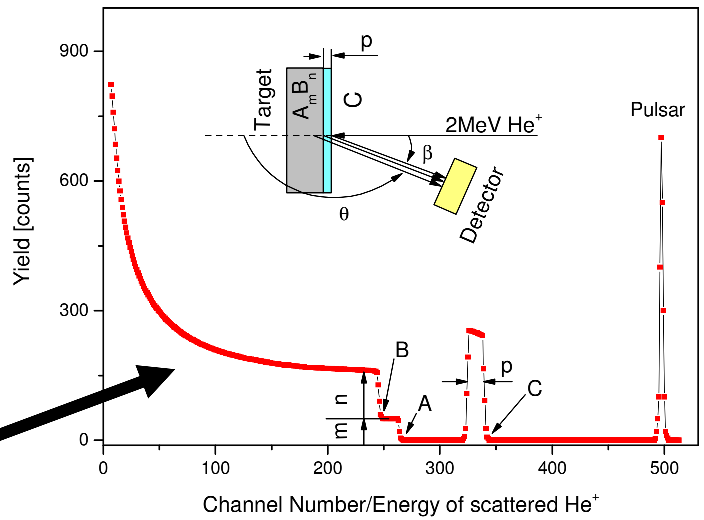
σ – scattering cross section

α = incident angle
β = exit angle
θ = scattering angle

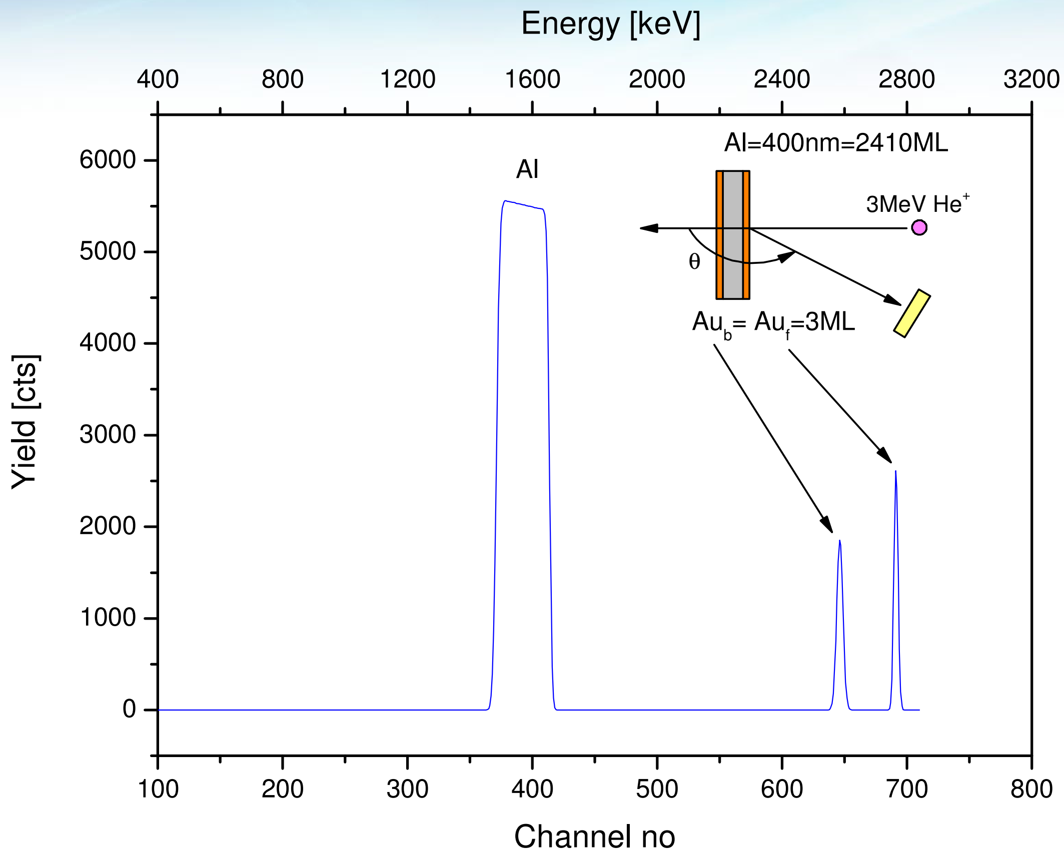


Applications:

- Elements heavier than the projectile
- Mostly suitable for heavy elements in a light elements matrix
- Depth of analysis: few nm up to few μm
- Depth resolution: few 10nm
- Sensitivity: few at% for light elements; few 100ppm for heavy elements



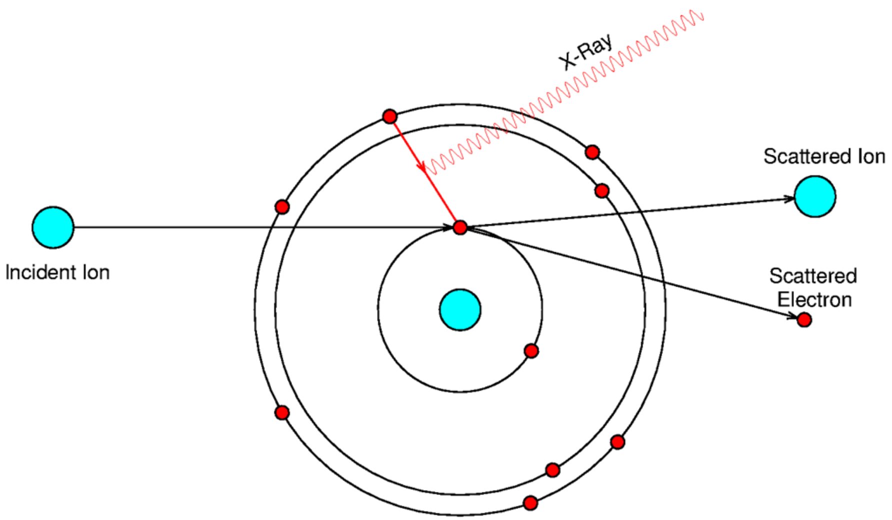
RBS Example

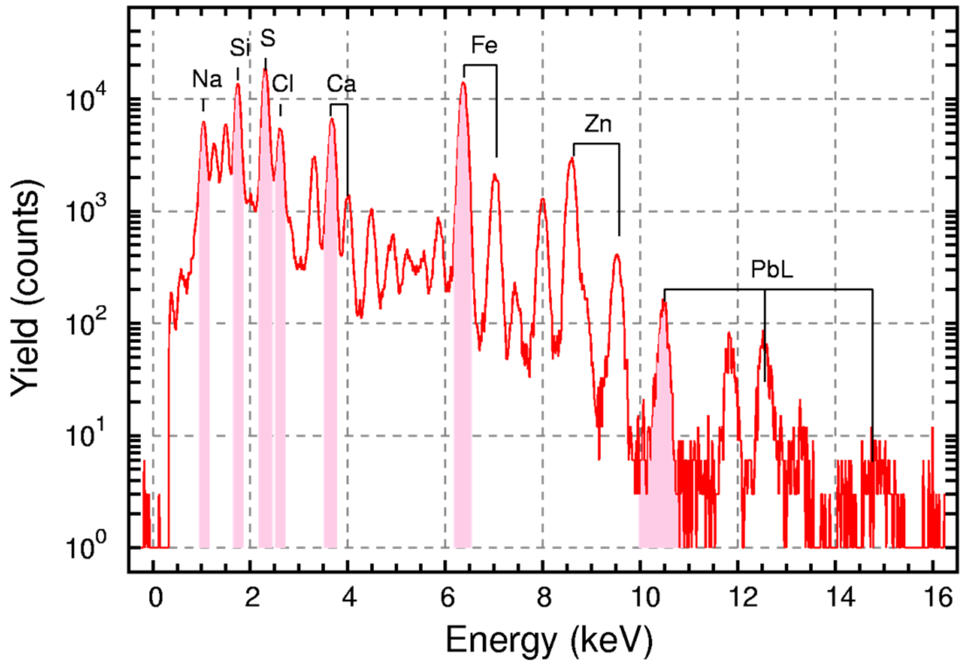


RBS spectrum (θ = 170^o) for 3.0 MeV He^+ ions incident on a 400 nm Al film with thin Au markers on the front and back surfaces

Proton Induced X-Ray Emission (PIXE)

Applications: Trace element (Al to U) composition of particulates and bulk materials





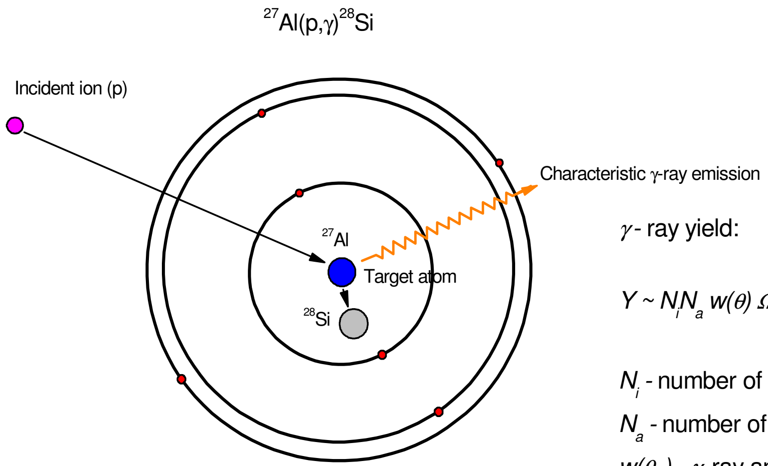
- Optimum sensitivity near Fe (1ppm)
- Elemental sensitivities range 1-100 ppm
- Typical proton depth range 20-50 microns

Proton Induced Gamma Emission (PIGE)

Applications:

- Trace analysis of light elements (Li to Al) in particulates, bulk materials and thin films
- Sensitivity element dependent, typical < 1 ppm for F; < 40 ppm for Al and Na

In PIGE the γ-rays generated from nuclear reactions are detected



γ- ray yield:

$$Y \sim N_i N_a\, w(\theta)\, \Omega\, \varepsilon\, S/E_r$$

N_i - number of incident ions

N_a - number of target atoms

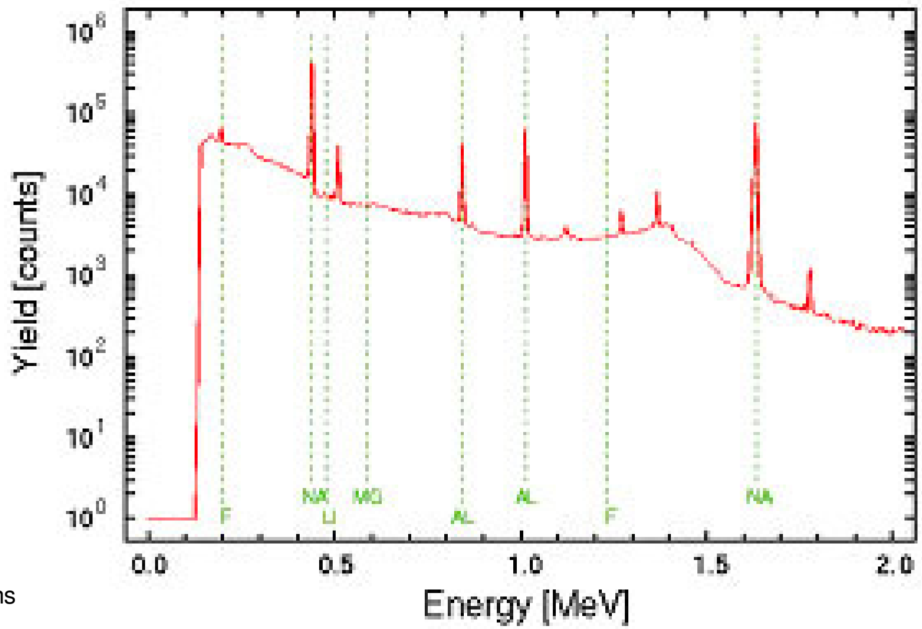
$w(\theta)$ - γ-ray angular distribution

Ω - detector solid angle

ε - detector efficincy

S - resonance strengths

E_r - resonance energy



Typical PIGE spectrum of light elements (Li, F, Na, K, Mg, Al)

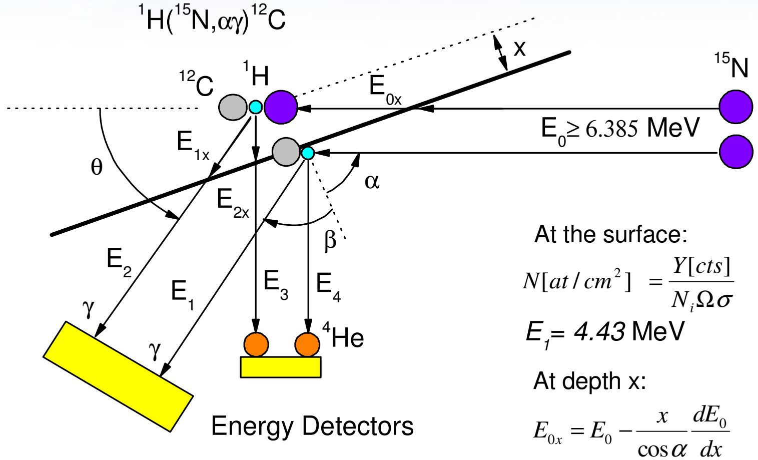
Examples: $^{27}Al(p,\gamma)^{28}Si$ $^{19}F(p,\alpha\gamma)^{16}O$

Nuclear Reaction Analysis (NRA)

Applications:

- Depth profiling of light elements: H-Si
- Depth of analysis: few nm to few µm
- Depth resolution: 5-20nm
- Sensitivity: 1-100ppm
- Applicable for crystalline & amorphous

Target Element	Input Beam	Resonance Energy [keV]	Max. Energy [keV]	Input Beam Current	Max. TV [MV]	E_γ [MeV]
^{7}Li	^{1}H	2,060	5,000	500nA	2.5	16.15
^{10}B	^{4}He	2,400	5,000	400nA	2.5	3.8
^{16}O	^{4}He	3,040	6,000	400nA	3	1.6
^{1}H	^{15}N	6,385	15,000	200nA	4	4.43



At the surface:

$$N[at/cm^2] = \frac{Y[cts]}{N_i \Omega \sigma}$$

$E_\gamma = 4.43$ MeV

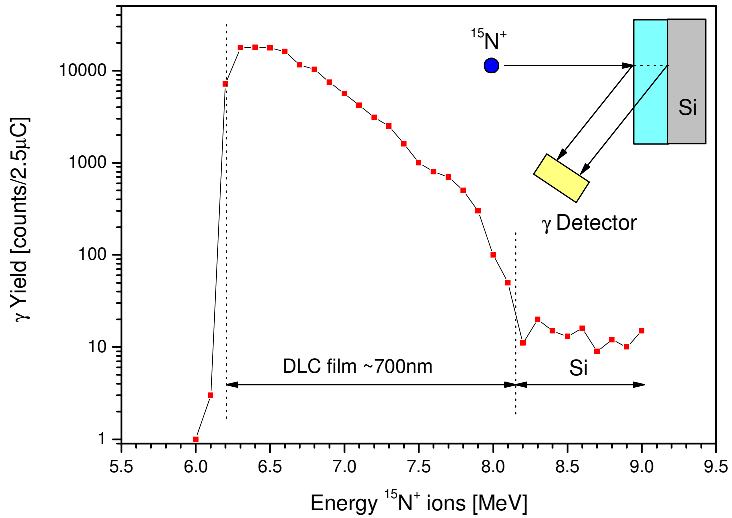
At depth x:

$$E_{0x} = E_0 - \frac{x}{\cos\alpha}\frac{dE_0}{dx}$$

$$E_2 = E_{1x} - \frac{x}{\cos\beta}\frac{dE_{1x}}{dx}$$

$$N[at/cm^2] = \frac{2Y[cts]\frac{dE}{dx}}{\pi N_i \sigma \Gamma}$$

N_i - number of ions incident on sample
Ω – detector solid angle
σ – ^{15}N reaction cross section
Γ – FWHM of resonance (1.8keV)

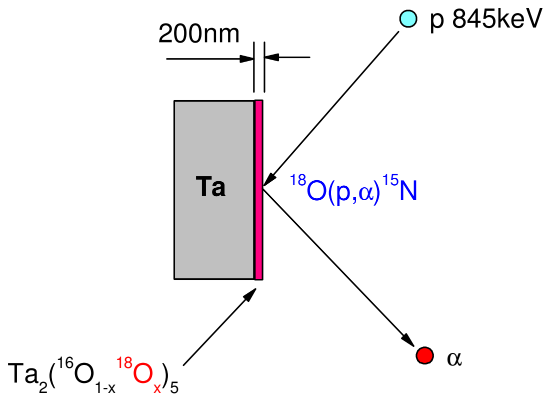


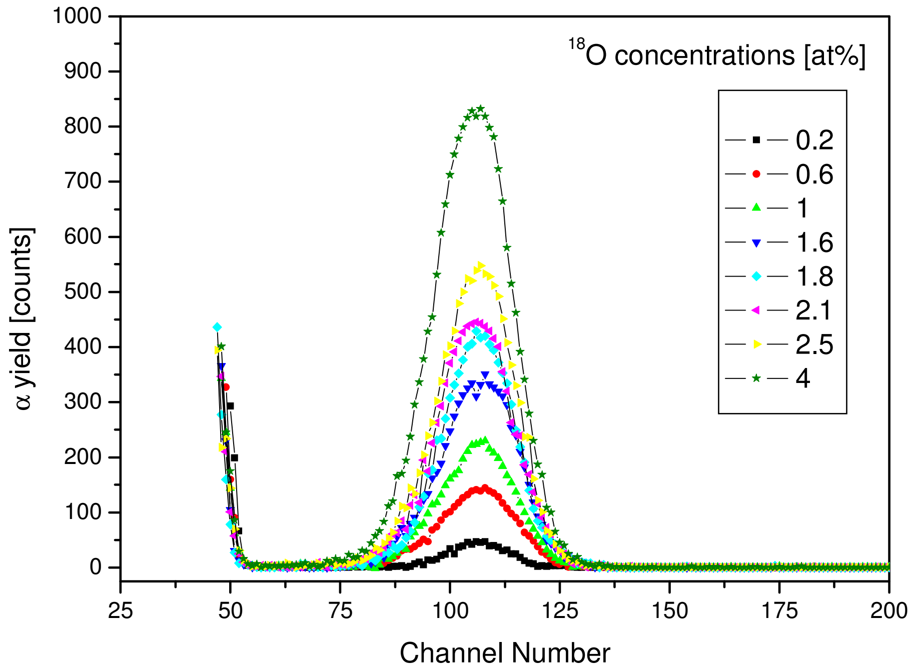
Samples:

- Thick DLC film grown by DC-PACVD on Si(100) using CH_4 and C_2H_2 to vary Hydrogen
- Hydrogen content plays a role in the biologic response
- Hydrogen content is higher at the surface and decreases toward the interface

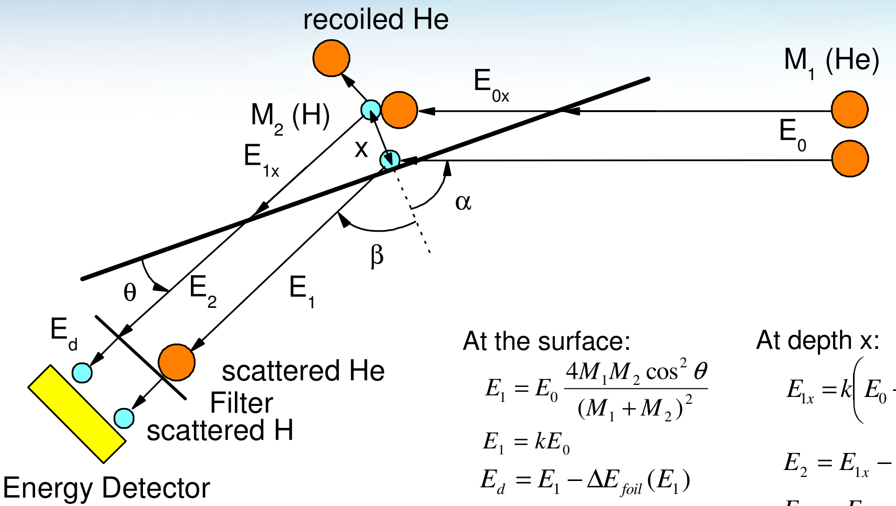
NRA example: Oxidation kinetics of Ta

Sample: $Ta_2{}^{16}O_5$ film 200nm thick on polycrystalline Ta exposed to ^{18}O
Result: ^{18}O depth profile





Elastic Recoil Detection Analysis (ERDA)



At the surface:

$$E_1 = E_0 \frac{4M_1M_2\cos^2\theta}{(M_1+M_2)^2}$$

$$E_1 = kE_0$$

$$E_d = E_1 - \Delta E_{foil}(E_1)$$

At depth x:

$$E_{1x} = k\left(E_0 - \frac{x}{\cos\alpha}\frac{dE_0}{dx}\right)$$

$$E_2 = E_{1x} - \frac{x}{\cos\beta}\frac{dE_{1x}}{dx}$$

$$E_d = E_2 - \Delta E_{foil}(E_2)$$

$$N[at/cm^2] = \frac{Y[cts]\cos\alpha}{N_i\Omega\frac{d\sigma}{d\Omega}}$$

$$\frac{d\sigma}{d\Omega} = \frac{[Z_1Z_2e^2(M_1+M_2)]^2}{4E_0^2M_2^2\cos\theta}$$

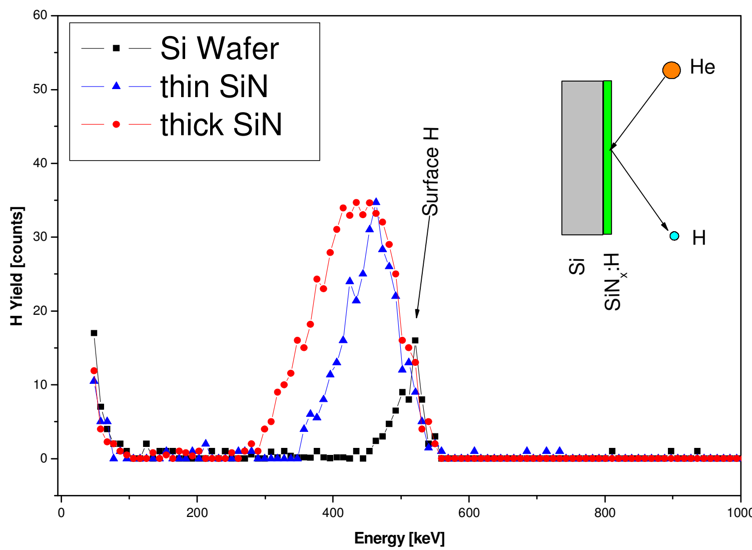
N_i - number of ions incident on sample
Ω – detector solid angle
σ – scattering cross section

Applications:

- Elements: lighter than the projectile
- Depth of analysis: up to few 100nm
- Depth resolution: few 10nm
- Sensitivity: 0.1 at% to few at%

There are three options for the type of energy detector:

- SB detector
- dE-E detector
- Time-of-flight detector



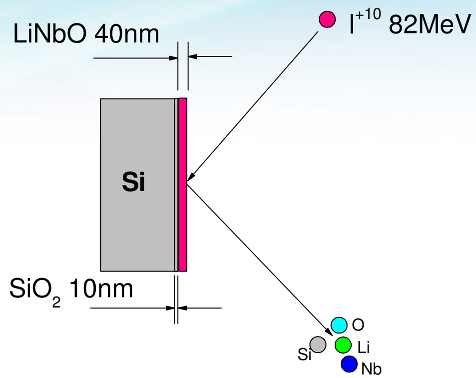
ERDA example:82 MeV I and ToF detector

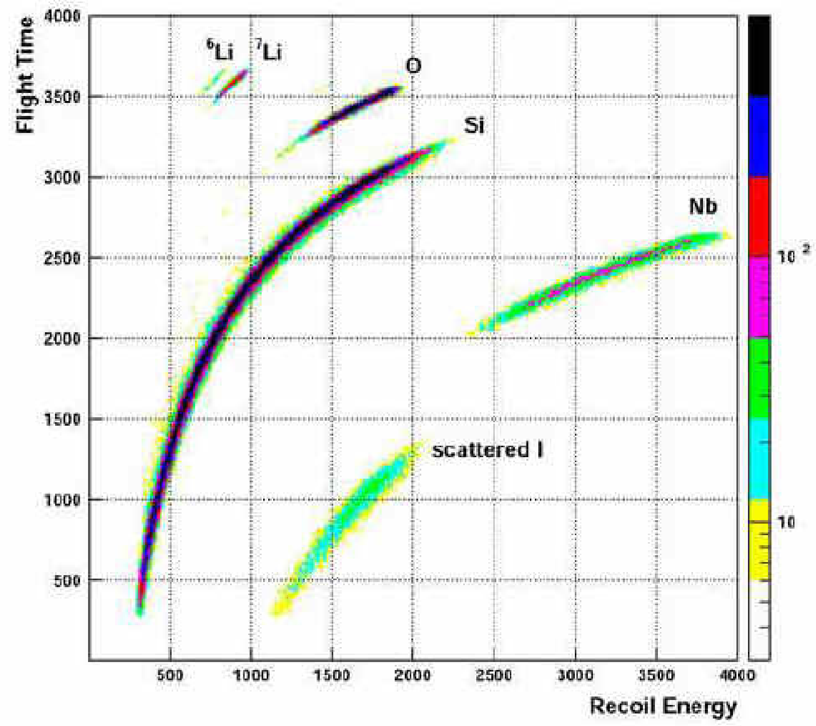
Sample: LiNbO/Si(100)

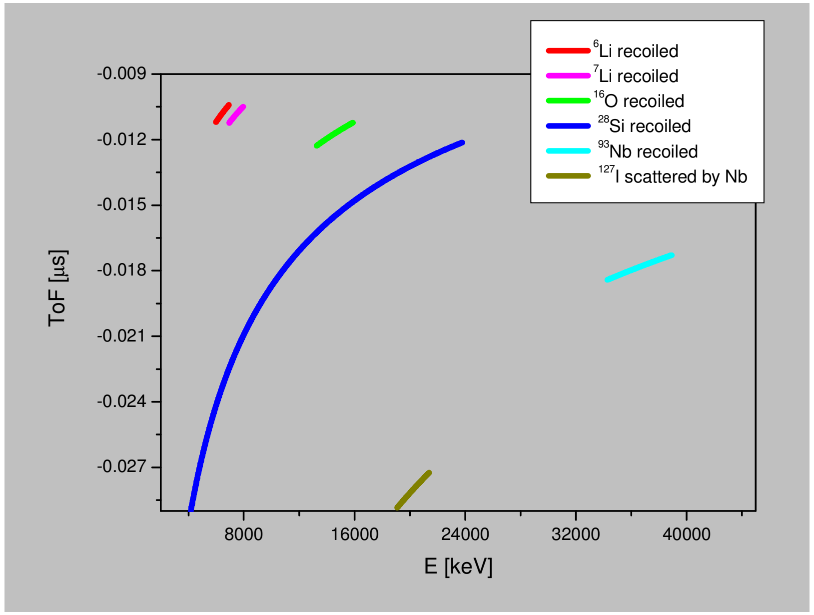
Results: Film thickness ~100ML

~6ML SiO_2 present at the interface

Nb diffusion in Si



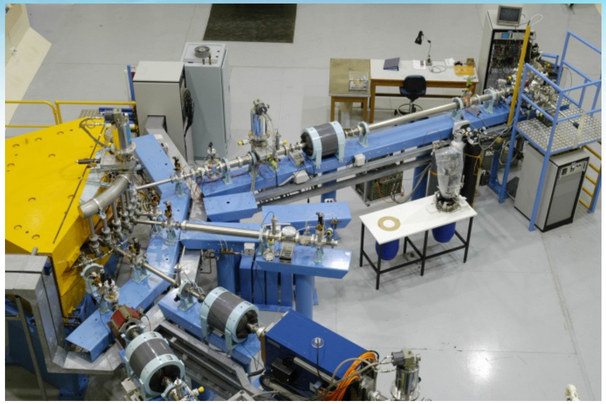




Quasi Mono-energetic neutrons

$^{7}Li(p,n)^{7}Be$

Max E p = 20 MeV
Max E n = 18 MeV
Max n Flux ~ 10^8 n/cm^2



- Number of n produced:

$$dN = ig\rho_{Li}\frac{d\sigma}{d\Omega}E_p dx d\Omega$$

Where: i – ion beam current [μA]
g –no of protons/μA
ρ_{Li} –density of ^{7}Li
$d\sigma/d\Omega$ -differential cross section in the lab frame
E_p -energy of protons

Applications:
Isotope production, study of nuclear reactions, study of nuclear materials, etc.

- Energy of n:

$$E_n = \frac{m_p m_n}{(m_{Li}+m_n)^2}[\mu \pm \xi]^2 E_p$$

Where: $\mu = cos\theta$; θ -n direction in the lab frame;

$$\xi^2 = \sqrt{\frac{m_{Li}(m_{Li}+m_n-m_p)(E_p-E_{th})}{m_p m_n E_p}+\mu^2-1}$$

E_{th} =1.881MeV for ground state reaction
E_{th} =2.378MeV for excited state reaction

Thanks for your interest!

Nuclear-based science benefiting all Australians